[JANUARY, 1891.]

THE

TRANSACTIONS

OF THE

ROYAL IRISH ACADEMY.

VOLUME XXIX.—PART XIV.

CONTRIBUTIONS TO A KNOWLEDGE OF THE GRANITES OF LEINSTER.

BY W. J. SOLLAS, LL.D., D.Sc., F.R.S., Professor of Geology and Mineralogy, University of Dublin.

DUBLIN:
PUBLISHED BY THE ACADEMY,
AT THE ACADEMY HOUSE, 19, DAWSON-STREET.
SOLD ALSO BY
HODGES, FIGGIS, & CO., GRAFTON-STREET.
AND BY WILLIAMS & NORGATE,
LONDON: 14, Henrietta-street, Covent Garden. | EDINBURGH: 20, South Frederick-street.
1891.

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XIV.

CONTRIBUTIONS TO A KNOWLEDGE OF THE GRANITES OF LEINSTER.

By W. J. SOLLAS, LL.D., D.Sc., F.R.S., Professor of Geology and Mineralogy, Dublin University.

[Read November 30, 1889.]

Historical.—The granite of Leinster, besides its exposure in several isolated strips and patches, is continuously displayed, with monotonous uniformity of character, over an area some 600 square miles in extent, ranging from the sea-level to a height of 3000 feet; it is considerably the largest mass of granite exposed in the British Isles, and has naturally been made the subject of numerous investigations, as the long list of papers dealing with it, given at the end of this communication, will testify.

So early as 1819 the general characters of the granite were admirably described by Weaver (29),* who, amongst other valuable observations, noticed the restriction of gneiss, when this rock occurs in Wicklow, to the junction of the granite with the surrounding mica-schists, a phenomenon which subsequently received very close attention, and was in part at least the source of the once fashionable theory of the "metamorphic" origin of granite; for it was soon observed not only that the gneiss passes insensibly into the granite, but that one is evidently only a structural modification of the other, only by what we should call a strange contradictoriness, were not such so strangely frequent, their relations were inverted, and the granite was regarded as the product of the gneiss, the foliation of which was interpreted as a vestigial structure, representing the lamination of the shale, or the cleavage of the slate, from which it was supposed that the gneiss, and consequently the granite, had been derived; it is only in quite recent times that this gneissose structure has received its true explanation as a subsequently produced character, resulting from internal shearing under great pressure of the previously consolidated granite (26, 28).

* *Vide* List of Authors, at page 513.

A more exact inquiry into the mineral composition of the granite, destined to have very fruitful results, was initiated in 1853, by a note by Dr. Kane (17), in which he states that numerous observations, and more particularly analyses of some natural waters derived from the granite led him to suspect that the felspathic constituent of the rock was a species of albite, and that orthose was merely of exceptional and local occurrence. Kane had certainly hit upon an important fact, viz. the presence of soda-felspars as characteristic constituents, but his observations were less extensive than his conclusion, and he went too far in giving to orthose too subordinate a *rôle;* his views were immediately controverted by Apjohn (1), and later by Galbraith (3), who showed by numerous analyses that the most conspicuous felspar in the rock was a potash felspar, and these observers were therefore led to regard orthose as the only important felspar present, wherein they also went too far, the truth being that soda and potash felspars are both present, and in about equal proportions. Galbraith, wishing to ensure a fair sampling of specimens for analysis, collected felspar crystals from seven different localities fairly evenly distributed between Dalkey and Glenmalure, a distance of thirty-six miles. He thus eliminated locality as a disturbing factor, but another and far more important factor remained unsuspected, and that was the relative size of the crystals. Galbraith naturally chose the largest and finest as being most suitable for analysis, but in so doing he ensured the absence of any large proportion of soda felspars, since in the porphyritic granite of the main mass the large felspar crystals are invariably that characteristically potash-bearing felspar—microcline. In this way, as she so frequently will, Nature "forced a card" upon the observer, and at that epoch he might be relied on to accept it.

The work of Galbraith was preceded and followed by the investigations of Haughton (7–12), who by his elaborate chemical analyses and mathematical reasoning laid the foundations of an exact knowledge of the subject.

In these works of Haughton we find for the first time a complete quantitative estimate of the mineral composition of an igneous rock, and that such a complex one as granite. It is worth noticing that the original estimate published in 1856 (7), has been subsequently amended in

correspondence with fresh discoveries, so that the latest approaches far more nearly to the truth than the earlier estimates. I particularly mention this as the earliest estimate is that quoted in text-books, and I had myself overlooked the important changes made in the latest estimate, till the bulk of this paper was completed. I give here the different estimates in parallel columns:—

	1856.	1858.	1880.
Quartz,	24·98	27·66	32·57
Felspar,	61·18	52·94	Orthose, 15·44
			Albite, 22·10
White mica,	13·37	14·18	19·16
Black mica,		5·27	5·81
Paste,			4·92

Another very important result established by Haughton is the distinction between the granite of the main chain and of the isolated exposures, founded on differences in their chemical composition, the bulk analysis of the latter being characterized by a predominance of soda over potash, and of the former of potash over soda.

The determination of the large felspar crystals of the porphyritic granite as microcline was made by Prof. O'Reilly (23), and the addition of iolite to the list of minerals enumerated by Weaver, by Mr. Joly (14).

Haughton had advanced our knowledge as far as it could be pushed without the aid of the microscope, and new methods of mineral separation. In the present paper an attempt is made to apply these, in the light shed by the investigations of Rosenbusch and Zirkel on the granite of other districts, to a further elucidation of the subject. No one has hitherto made a close microscopical examination of the rock, with the exception of Professor Hull (13), whose paper may be regarded as an interesting curiosity in petrographical literature.

METHODS.—The separation of the constituent minerals of the different specimens of granite was accomplished as follows:—A fragment of the rock was first crushed in a steel mortar and passed through a series of sieves. When it had all gone through the finest of these, having sixteen meshes to the square mm., it was levigated in water till

the finest "flour" was removed, then dried and placed in Thoulet's solution in a Smeeth separator.* As originally designed, the urn-shaped upper half of this apparatus was too obtusely angled—a better form is that shown in the accompanying illustration (fig. 1). To secure as complete a separation as possible, the separator is placed in a rack in a half reclining position. By this means the floating material is distributed over a larger surface than when the vessel stands vertical. When the precipitation of the heavier minerals appears to be complete, the apparatus is placed upright; the heavier grains lying on one side slide down to the bottom, and the lighter rise up on the other side to the top. The disturbance which the main mass of floating material at the same time experiences tends to set free any heavier grains that may be entangled in it, and these fall with the descending current to the bottom: in this way, by one operation, an approximate separation may be obtained, but in all cases when a particular mineral is to be isolated for analysis, the process of separation must be repeated on it at least once, and when great accuracy is required twice. In treating the granite the whole of the prepared material was placed at once in fluid having the specific gravity of calcite (2·715). The felspars and quartz were thus separated from the micas and rarer constituents; the further separation of the several species of felspar from each other and from quartz was carried on in one separator, and that of the micas and heavy minerals in another, a great saving of time being thus effected. The determination of the specific gravity of the various strengths of Thoulet's solution was made partly by indicators and Westphal's balance, and partly by means of hydrostatic floats. The floats are made by drawing out a thin piece of glass tubing to a long capillary termination at one end, sealing it at the other and then charging it with mercury. On immersion in a fluid it may be made to float vertically by adjusting the charge of mercury, and of course the distance between the

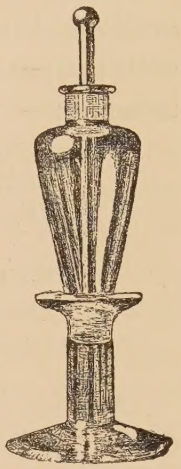


FIG. 1 (× ¼).

* Scientific Proceedings, Royal Dublin Society, Vol. VI. (N. S.), p. 58.

end of the capillary termination and the surface of the fluid will vary with the density of the latter: this distance can be very accurately read off on a graduated mirror. To calibrate the float it is placed in solutions of known densities, and a table constructed correlating these with the distances by which the float rises above the level of the fluid; intermediate densities and distances can then be introduced by interpolation. By this method and using a series of floats, results can be attained accurate to the third place of decimals much more quickly than with Westphal's balance, and with the use of a much less quantity of heavy fluid—a saving in some cases of great advantage. To diminish the irregularities resulting from the tapering form of the capillary near its origin in the main tube, a separate capillary thread taken from the middle of one drawn out from a thicker piece of tube may be made to take its place; there is no difficulty in breaking off the original capillary near its base and fusing the more uniformly thick one on.

The method usually employed for determining the specific gravity of a powdered mineral is an exceedingly tedious one; in place of it I used an adaptation of a process which I have previously described.* Briefly, this is as follows: Thoulet's solution is prepared of two different strengths, one heavier and the other lighter than the mineral to be examined; the heavier is first poured into a glass tube and then the lighter upon it. The tube and its contents are left to stand for diffusion to take place, and in this way a diffusion column of gradually diminishing specific gravity from below upwards is obtained. Two index minerals, of which the specific gravity is accurately known, one heavier than the mineral under examination and the other lighter (the differences being the least possible), are then introduced; they float, each at a height corresponding to its specific gravity. The powdered mineral—the specific gravity of which it is required to determine—is then added; it floats in a zone situated somewhere between the index minerals, and at a distance from each proportionate to its difference in density. The heights of the different minerals can be read off against a graduated mirror. The obvious objection that one may not be sure that the change in

* Scientific Proceedings, Royal Dublin Society, Vol. IV. (N. S.), p. 381.

specific gravity of the fluid on passing from one mineral index to the other is uniform is met by making the experimental tube in the shape of a prism and observing the shape of the spectral bands which are then visible on looking through it; at first, directly after the fluids are introduced, a sudden flexure of the spectral bands will be observed at the junction of the two fluids, but after standing a few hours this disappears, a regular curve takes its place, and after a time the bands become quite straight, slanting obliquely from above downwards. We can have no doubt that at this stage the density of the fluid changes regularly from top to bottom of the column; having ascertained this there is no need to always employ a prism, which is difficult to dry and clean. All that is necessary is to wait a sufficient length of time before taking a reading, six or seven hours if the determination has been properly carried out will usually suffice.* By this means the specific gravity of a powdered mineral can be obtained with far greater ease than by the ordinary plan, and it has further the great advantage of indicating the purity of the separated mineral; if, for instance, one wishes to isolate a felspar of specific gravity 2·618, success will be shown by all the grains introduced into the specific gravity tube floating at the same level. If the separation has been only partially complete, stragglers will be observed floating at higher or lower levels, an observation of which will indicate the direction in which we must adjust the density of our fluid for a fresh separation. It might naturally be concluded that by taking all precautions, examples of minerals almost absolutely pure would be obtained, but this is far from being the case; our results are never more than approximate, take what pains we may. Intruders abnormally light owing to the presence of included cavities it may be, or of some other material, or abnormally heavy owing to some heavier inclusion, will intrude themselves into the zone of apparently pure material; still, with well prepared material, these unwelcome intruders are

* It might prove of great convenience if we could determine the specific gravity of Thoulet's solution indirectly by means of its refractive index, but in some experiments I made with this object I found that the fluid, with time, underwent molecular changes, which, independently of its density, altered its refractive index to such an extent that I had to abandon all hopes of succeeding with this method.

not very common, as a microscopical examination will prove, and the results of our analyses of carefully separated minerals must be very close approximations to the truth.

The readiest method of determining the species of felspar present in a granite and even also approximately the proportions in which they occur is furnished by a diffusion column; a store of bottles containing Thoulet's solution of different densities is kept in the laboratory, the most convenient densities being 2·715, 2·68, 2·65, 2·64, 2·6, 2·57, 2·52; a layer of each of these is carefully poured into a test tube in the order given, so as to form a succession of layers, each about a quarter of an inch deep or a little more. As reference minerals calcite, quartz, oligoclase (sp. gr. 2·638), microcline, and orthoclase, are introduced; then as much of the powdered rock as will lie on a six-pence; after standing an afternoon, the component minerals will be found perfectly sorted out, the micas will have sunk to the bottom, a few stragglers of heavy felspar will be found (along with impurities) between the calcite and the quartz, the quartz will form a well-defined disc, and above it will follow a fairly definite ring of oligoclase, its position depending chiefly on the amount of calcium it contains; stragglers then extend up to the orthoclase, or microcline, which forms the highest lying zone.

The index minerals are prepared by breaking up as homogeneous a crystal as can be selected into grains about 2 mm. in diameter; these are well boiled in distilled water and then thrown into Thoulet's fluid, which is rendered of the same density as the majority of the fragments. If, as happens in some cases—as, for instance, when oligoclase is selected—the grains are found to vary in density, then a separation should be made and those of the same density selected. These are then washed and stored in Thoulet's fluid, from which they are taken as wanted; by thus storing them air bubbles are prevented from forming when they are introduced into the diffusion column.

I believe the character of the felspars of a rock can be more rapidly and easily determined in this way than by any other process. It is an invaluable preliminary to commencing a complete separation of a rock.

Mineral Constituents of the Granite.

ZIRCON (Fig. 2).—This occurs as minute colourless transparent crystals, presenting the usual combination of the forms (111), (100), and more rarely also (311); traces of zonal structure are indicated by faint lines having a slightly different refractive index to the mass of the crystal; small gas cavities, frequently large as compared with the size of the crystal, and rendered very obvious by the characteristic broad dark margin, are far from rare; they are always of rounded outline, never taking the form of their host. Glass inclusions, such as have been described by Chrustschoff, have not been met with. Zircon is a never-failing constituent of the Leinster as of all other granite; its minute but exquisitely definite crystals are scattered broadcast through the rock, so that no single slice prepared for the microscope but exhibits many of them. It is found included in all the other primary constituents, with the doubtful exceptions of apatite and magnetite, a consequence of the early stage at which it consolidated from the parent magna; its true home, however, seems to be within biotite, which always presents around it the well-known highly pleochroic aureole. When present in other minerals, such as quartz, it indicates the solution of the biotite in which it was originally enclosed. Early as the zircon made its appearance it was preceded, however, by another mineral of undetermined composition, which occurs as minute elongated rods with more or less rounded ends enclosed within the zircon: this may possibly be rutile.

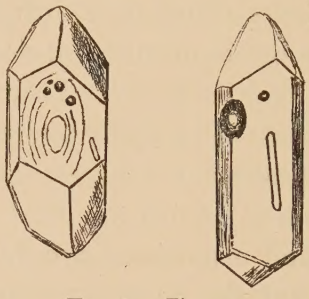


FIG. 2.—Zircon.

APATITE (Fig. 3).—This presents itself as prisms of very variable length, the longer forms characterized by the usual transverse jointing parallel to the chief cleavage planes (111), the shorter, with well defined terminations constituted by the basal and pyramidal faces. Zonal structure is not infrequently present, the outlines of the successive zones being conformable with that of the exterior (Fig. 3, *b*); the central core (Fig. 3, *a* and *c*) is sometimes evidently coloured with a faint violet tint,

while the rest of the crystal is colourless; very small individuals no larger than the core are coloured throughout with the same violet tint. This coloured apatite is pleochroic, the absorption for the extraordinary rays being greater than that for the ordinary. Gas cavities (Fig. 3, *d*, *f*) are frequently present, sometimes with a rounded form, sometimes rudely repeating that of the host; in addition microliths of an undetermined mineral occur. Some of these have much the appearance of zircon; they occur as slender prisms (Fig. 3, *e*), sometimes lying coaxially with the apatite, sometimes not; they are rounded at the ends with a marked tendency to become pointed, and they differ considerably in refractive index from the apatite. Owing to their minuteness it was not possible to come to any conclusion as regards the character of their double refraction. They extinguish parallel to their long axis. Apatite, though present in most of the constituents of the granite, chiefly occurs in the biotite; in association with zircon it evidently crystallized out at a very early stage, but whether before zircon or not it is impossible at present to say definitely. In the Leinster granites, as in other igneous rocks, a pleochroic aureole is as constantly absent from the apatite enclosed in biotite as it is invariably present around the zircon.

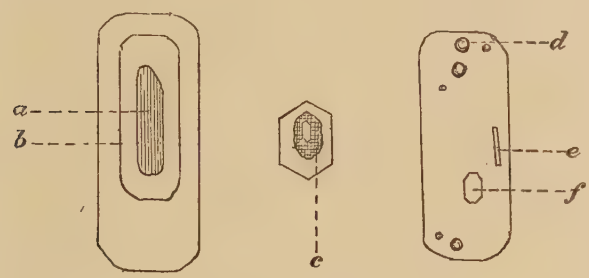


FIG. 3.—Apatite.

BIOTITE.—This occurs in idiomorphic plates rarely bounded by definite crystalline outlines, and in corroded fragments, very generally enclosed in muscovite, as will be presently described, but also in all the subsequently formed constituents of the rock, including quartz, within which it sometimes occurs as minute round or oval discs very similar in appearance to blood corpuscles. As stated by Haughton, it is uniaxial, *i. e.*, so far as can be determined without specially refined methods of observation. At the same time, I should mention that I have occasionally met with flakes from an otherwise quite uniaxial crystal, in which an angle of from 12° to 16° was measured between the optic axes.

The black mica of the Leinster granites must be assigned to the species Haughtonite, which, as shown by Heddle (*Mineralogical Magazine*, Vol. III., p. 72, vol. IV., p. 221), is characterized by containing a large amount of ferrous oxide, which takes the place of magnesia. It thus differs from other species of Lepidomelane, in which the iron is in the ferric state and replaces alumina. In the following table is given an analysis which I have made of Haughtonite separated from the soda granite of Aughrim. By its side appears one by Haughton of the black mica of Ballyellin, which occurs in large crystals one or two inches in diameter; then follows an average of fifteen analyses made by Heddle, and finally a very careful analysis of the same mineral from the gneiss of Freiberg, made by A. Becker (*Zeitschrift f. Krystallographie und Mineralogie*, Bd. 17, p. 130, 1889):—

ANALYSIS OF HAUGHTONITE.

	Aughrim.	Ballyellin.	Average of Heddle's Analyses.	Freiberg gneiss.
SiO_2	33·95	35·55	35·83	34·70
TiO_2	3·81	. . .	. . .	4·58
Al_2O_3	17·13	17·08	18·99	17·17
Fe_2O_3	2·44	3·55 *	4·14	2·11
FeO	21·18	23·70 *	16·78	19·05
MnO	. . .	1·95	0·78	0.50
CaO	2·03	0·61	1·46	
MgO	6·60	3·07	9·65	9·52
K_2O	7·12	9·45	8·46	8·91
Na_2O	2·83	0·35	1·07	1·24
H_2O	3·70	4·30	3·16	3·56
P_2O_5	0·68	. . .	. . .	. . .
Fl	trace	. . .	. . .	0·20
Total, . .	101·47	99·61	101·32	101·54

The material investigated by Becker appears to have been of exceptional purity. He speaks of it as "absolute tadellosem material," and

* In the published analysis of the mica, the ferrous oxide is given as 3·55 °/₀, and the ferric oxide as 23·70 °/₀. This, I fancy (and Dr. Haughton agrees with me), must be an accidental inversion. I have reversed the proportions in the above Table.

adds, that it was investigated with the greatest possible care, as was evidently the case. Too much, therefore, must not be made of the close agreement with this of my analysis of the Aughrim mica, for although mine was conducted with great care (not with such exactitude as regards the estimation of Titanium oxide), yet the material was certainly not of absolute purity—a little sphene, and some apatite, not quite 2 °/₀, judging from the phosphoric acid, and zircons, with their surrounding pleochroic halos (which cannot be of the same composition as the rest of the mica) were present, and could not be eliminated by any of the usual processes; the Ballyellin mica of Dr. Haughton, though very fresh, and apparently of great purity, yet exhibits under the microscope numerous inclusions of other minerals (epidote and others) together with abundant pleochroic halos.

In the following Table are given the atomic proportions deduced from the analyses of the preceding Table, and from two additional ones by Heddle, one (No. 4) with the lowest proportion of monad metals found by him, and the other (No. 5) with the highest:—

	1.		2.		3.		4.		5.	
Si	566	613	580	640	597		609		593	
Ti	47		60							
Al	336	366	338	364	354	411	433	463	327	350
Fe‴	30		26		57		30		23	
Fe″ . . .	294	479	265	515	251	516	222	505	250	521
Mn	. .		10		11		11		10	
Ca	20		. .		27		22		49	
Mg	165		240		227		250		212	
K	151	653	190	630	181	580	176	368	211	849
Na	91		40		36		25		4	
H	411		400		363		167		634	

1. Aughrim; 2. Freiberg; 3. Average of Heddle's analysis; 4. Heddle; 5. Heddle, *loc. cit.*

In the reduction of the Aughrim mica the phosphoric acid (0·68°/₀) and as much lime (0·9 °/₀) as is computed to have existed in combination with it as apatite, have been deducted, but no allowance has been made for titanic acid in combination as sphene, partly because it is impossible to say how much of it belongs to the sphene and how much to the mica, and partly also because even that which is present in the sphene may have originally been derived from the mica itself.

From the preceding Table it will be seen that the analysis of the Aughrim mica furnishes the following proportions:—

	Si	Ac	Ms	Ha
	613	366	479	653
Divided by 102, . . .	6	3·58	4·68	6·38
Or whole numbers, . .	12	7	9	13

The empirical formula* is therefore $Si_{12}\ Ac_7\ Ms_9\ Ha_{13}\ O_{48}$.

It may be unfolded in the following way:—

$SiAcHaO_4$	7	7	. .	7
$SiMs_2O_4$	3	. .	6	. .
$Si\,(OMsOHa)_2O_2Ms$ . .	1	3	3	2
$SiHa_4O_4$	1	. .	. .	4
Or, 7 $SiAcHaO_4$; 3 $SiMs_2O_4$; $Si\,(OMsOHa)_2O_2Ms$; $SiHa_4O_4$.				

Becker obtains from his analysis of the mica of the Freiberg gneiss the empirical formula:—$Si_{11}\ Ac_6\ Ms_8\ Ha_{10}\ O_{44}$.

* The symbols R‴, R″, R′, used to denote triad, dyad, and monad elements are, owing to their similarity, very confusing, Tschermak avoids them, using instead the symbols Al, Mg, H, as signs of the groups to which they belong. This certainly renders his formulae more readily intelligible, but it is liable to mislead, and there are other obvious disadvantages in employing the same symbols in two different senses. I have, therefore, substituted fresh symbols to represent the Al, Mg, and H of Tschermak, constructing them by retaining the initial letter of Tschermak's symbols, but changing or adding a second, and this arbitrarily, though I believe I had in mind the termination "ic" in the symbol Ac, "ous" in Ms., and the first letter of alkali in Ha.

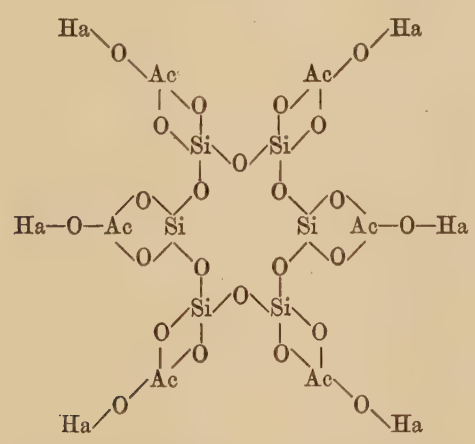
A slightly different result may be educed as follows :—

	Si	Ac	Ms	Ha
	640	364	515	630
Dividing by 106, . . .	6	3·41	4·83	5·91
Doubling, ...	12	6·82	9·66	11·82
And in whole numbers, .	12	7	9	12

This gives an empirical formula almost identical with that deduced from my analysis, differing only in the deficiency of one atom of Ha.

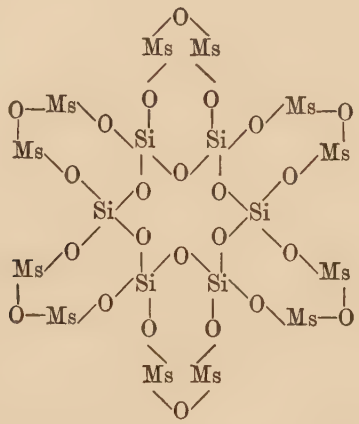
From the mean of Heddle's analyses we find $Si_6\ Ac_4\ Ms_5\ Ha_6$; from his analysis with a maximum of monad metals $Si_{12}\ Ac_7\ Ms_{10}\ Ha_{17}$; from that with a minimum of monads $Si_{12}\ Ac_9\ Ms_{10}\ Ha_7$.

We may now proceed to consider these results in the light of Tschermak's hypothesis.* The essence of this hypothesis appears to me to be the existence of a silica ring, the free affinities of which are satisfied by groups of the form $\begin{matrix} O \\ O \end{matrix}\!\!>\!Ac{-}O{-}Ha$, or of some other but corresponding form differing according to the species: thus in muscovite we have:—



* Tschermak: "Die Glimmergruppe. SB. d. kais. Akad. d. W. Math-natur. Cl. LXXVI. Bd. 1877.

in biotite, in addition to this molecule, another which, according to chermak, has the formula:—



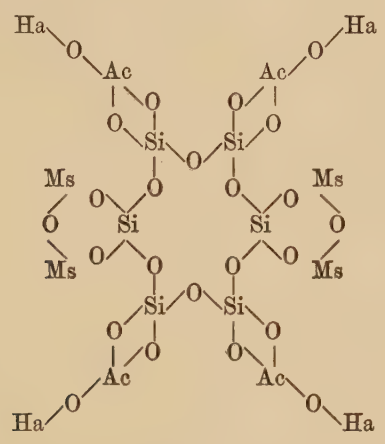
Representing the first molecule by K, and the second by M, the different species of biotite are to be explained as mixtures of the two in various proportions, thus: $K_m M_n$.

The molecule M, unlike that denoted by K, is not known to exist by itself as a mica, but its ultimate composition is the same as that of peridote, so that this ideal substance and peridote are at least polymeric.

The ratio of K to M can usually be expressed by whole numbers, and it would, therefore, appear that the two molecules do not occur together simply in the form of an admixture,* as Tschermak's method leads us sometimes to imagine; they are more probably united according to some law; but since they are chemically complete unions with no affinities unsatisfied, this cannot, according to Tschermak's method of representation, be the law of combination in multiple proportion. To bring the two structures of Tschermak into more intimate union is, however, a very simple matter. It is only necessary to make an interchange of radii, to convert the two dissimilar molecules with homogeneous radii into two similar ones with heterogeneous radii: thus the mica, which

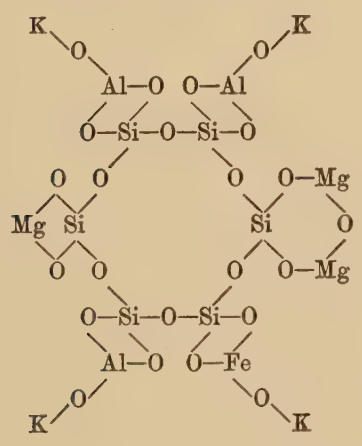
* This is still more strongly shown by the complete decomposibility of biotite by strong acids, which break up the stable aluminium rays as well as all the rest.

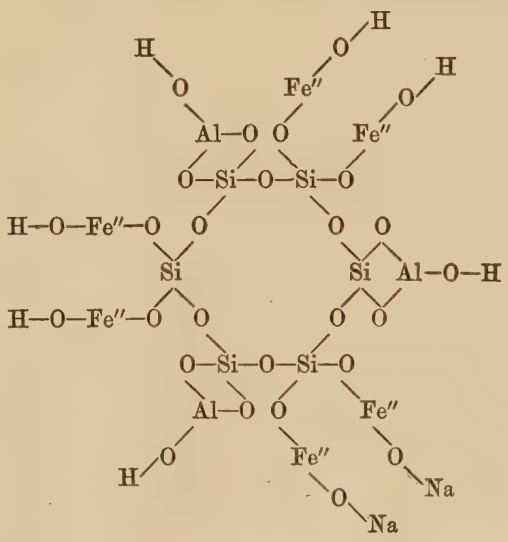
Tschermak would represent by the formula K_2M, would have the structure shown as in the following diagram:—



Frequently, however, the results of chemical analysis are too complicated to be represented by a single sexradiate ring, and it is necessary to make use of at least two such rings. I believe this results from the want of uniformity in composition of the mica, a change which can sometimes be proved to take place on passing from the margin to the centre of the same crystal.

The chemical structure of the Aughrim biotite may be represented in the following way: —





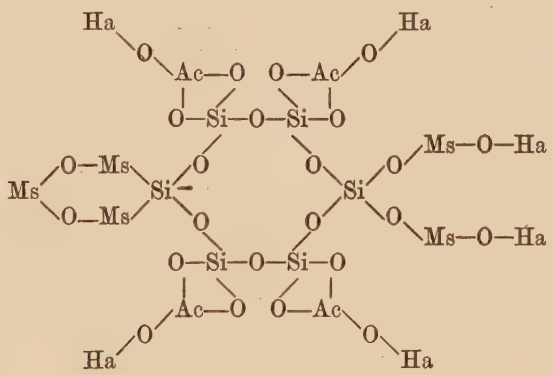
In order to distinguish the different rays of a molecule, we may number them from 1 to 6, commencing with the topmost one on the right hand, and proceeding in the direction of the hands of a watch. Using this nomenclature, it will be seen that the second and fifth ray of the first molecule are different, the structure of the second ray is normal, that of the fifth not, but this may merely indicate an error in the analysis, in the direction of deficiency of dyad bases.

In the second molecule, several of the rays (Nos. 1, 3, 5), have exchanged the form

$$\begin{matrix} \text{—O—Ms—} \\ \text{—O—Ms—} \end{matrix} \overset{\text{O}}{} \quad \text{for} \quad \begin{matrix} \text{O—Ms—O—Ha} \\ \text{O—Ms—O—Ha} \end{matrix};$$

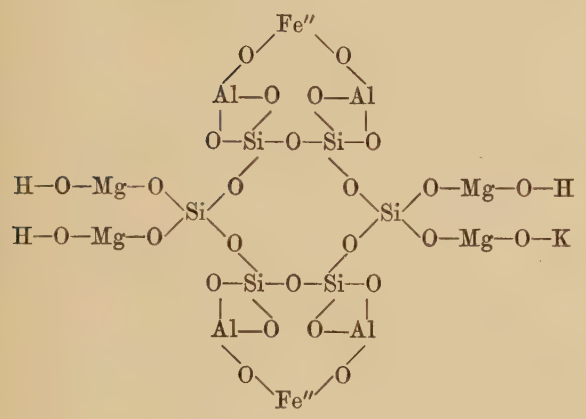
which is indeed the most usual one among the varieties of lepidomelane, possibly arising in most cases by hydration, to which the biotite ray, as might be expected from its resemblance to peridote in composition, is extremely liable.

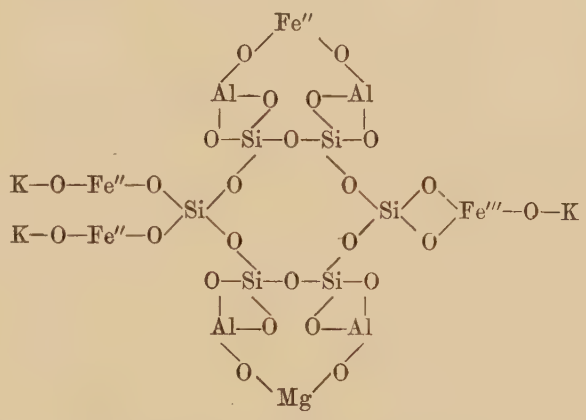
Proceeding to Heddle's analysis we obtain some very interesting results; the average gives the following ring:—



A new feature will be observed in the fifth ray, an extra molecule of OMsO being present, in a position homologous to that of the two molecules of HaO in the second ray opposite to it. It is possible that this should be associated rather with the aluminium than the magnesian rays; in either case it suggests a relation to the spinellids.

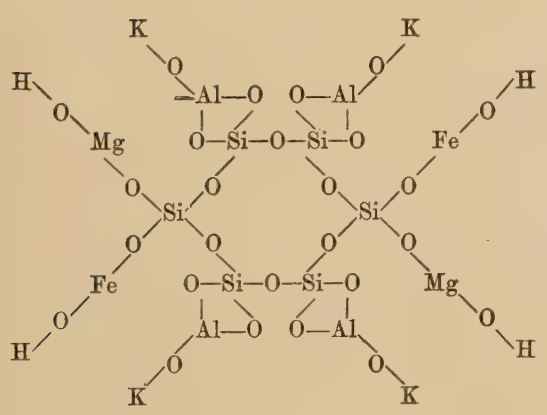
This feature occurs still more strongly pronounced in the formula which results from Heddle's analysis of biotite with a minimum of monad atoms, as will be seen from the following:—

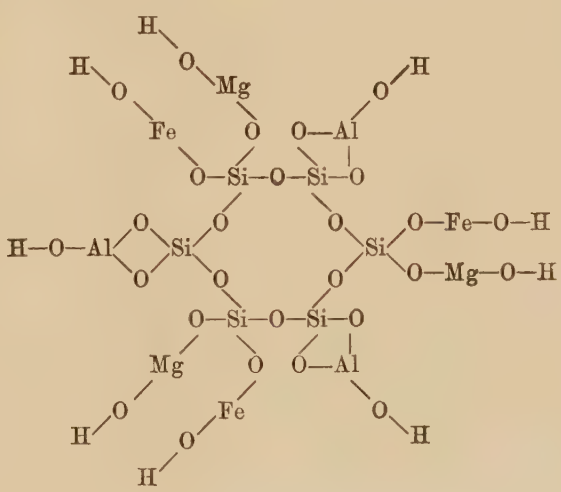




The interest of these formulæ would have been increased if Heddle had subjected his material to a careful microscopical examination before proceeding to an analysis, so as to ensure its purity. The proportion of ferrous iron in this remarkable mica is, however, so far in excess of the ferric that the suspicion of admixed magnetite may well be excluded.

We pass finally to that mica of Heddle's which contains the maximum of monad elements; its formula is as follows:—





In this, hydration appears to have reached the limits consistent with the maintenance of the mica character. A small quantity of soda was found in the analysis, but as it would only make half an atom in the above formula it is not indicated; to represent it the formulae would have to be doubled.

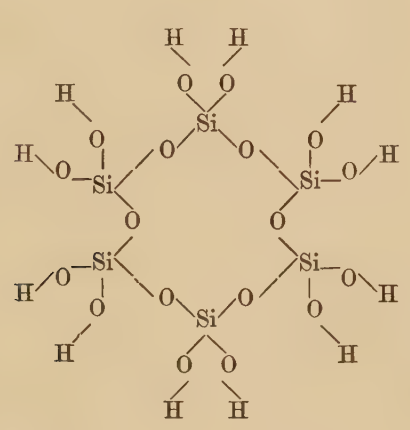
The foregoing instances are sufficient to illustrate the development of Tschermak's hypothesis as an explanation of the structure of Haughtonite; they show that the deductions from hypothesis are in accord with the results of analysis, and some of the results are very suggestive.

The partial resemblance of such atomic groups as $\begin{matrix} =Al—O— \\ =Al—O— \end{matrix}\Big\}Mg$ and $\begin{matrix} —Fe—O— \\ —Fe—O— \end{matrix}\Big\}Fe$ to magnetite is of interest when we recall that biotite immediately succeeds magnetite in order of consolidation, and one cannot help further suggesting, as Levy appears to have done, though not quite in the same language, that the pleochroic aureoles around included zircons are portions of the mica ring in which such rays predominate. Cohen's argument, attributing an organic nature to those aureoles, does not appear to me conclusive.

The alteration of biotite by secondary changes which cause it first to exchange its brown colour for green, and finally to lose it altogether, would naturally be explained as due to, in the first instance, a conversion of $\begin{matrix} —Fe— \\ —Fe— \end{matrix}\Big\}O$ rays into hydrates, such as —Fe—O—H, but it will be observed that the Aughrim biotite, which is a good brown colour, though very liable to turn green, possesses no more than two of the non-hydrated rays, and it is difficult to suppose that the hydration of these remaining two would lead to an entire change in colour. The final bleaching of the mica is possibly due to a substitution of —O—H for the —O—Fe—O—H group.

A noteworthy fact in the history of the biotite family is its behaviour when treated with strong acid, such as hydrochloric; all the bases are removed, and the silica remains, retaining in a most precise manner the original form of the mica; this is just such a result as might be expected to follow from its molecular structure, for this readily permits a complete

removal of the rays without destroying the coherence of the silica ring, which might be supposed when the attack of the acid is complete to possess the formula :—



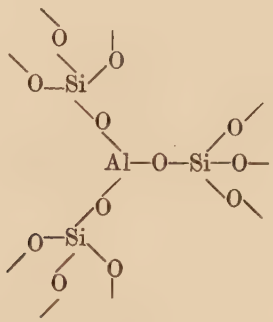
This is a suggestion capable of being put to the test of experiment. I find, however, that the residual silica, whether prepared by the action of concentrated hydrochloric acid at 100° C., or of dilute acid acting on the mica in the cold for several weeks, always possesses the specific gravity 1·98, and the corresponding composition, $Si_6O_{10}(HO)_4$.

Finally, the form of the mica molecule as here outlined is suggestive by reason of its general resemblance to the crystalline form of the mica; both are on the whole hexagonal, and the deviation of mica crystals from strict hexagonal symmetry is only consistent with the differences which exist in the structure of the rays of its molecules.

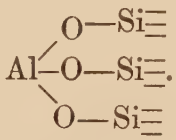
Tschermak's is not the only consistent system by which the structure of the micas can be explained, and since this Paper was read another theory has been propounded and supported with much acumen by Mr. F. W. Clarke.* In this, aluminium is regarded as the grouping element,

* American Journal of Science, Ser. III., Vol. XXXVIII., p, 384, 1889.

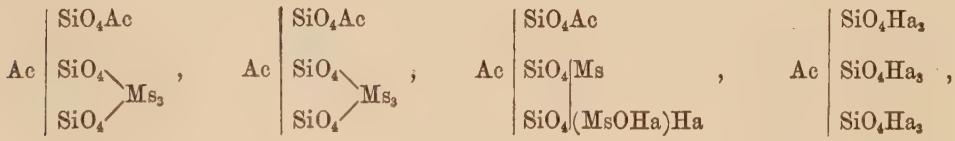
and to it are united three molecules of silicon tetroxyl, each with three unsaturated "bonds" and as these are differently satisfied so arise different species of mica. The following diagram will explain the structure of the "nucleus" of Clarke's molecule:—



Its triradiate character having been once exhibited we may for the future simply write—



This hypothesis fits the facts of analysis quite as exactly as Tschermak's; thus the constitution of Becker's mica would be represented as follows:—



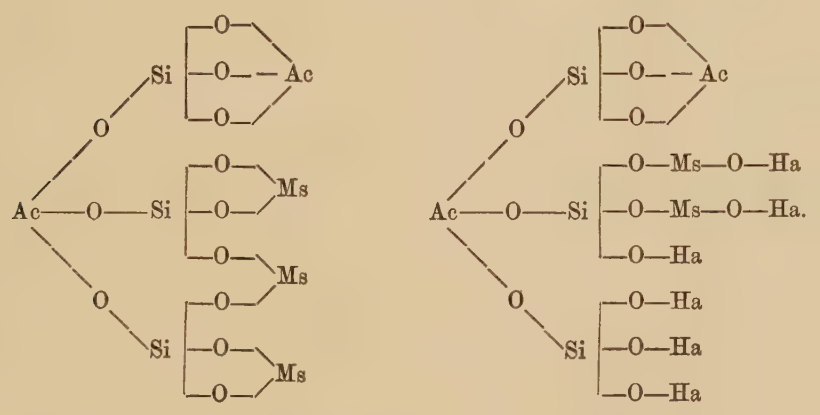
giving one molecule in which the ratio of aluminium to silica is as 1 : 3, and 3 molecules in which it is as 2 : 3.

The Aughrim mica, which contains one atom of a monad element less than Becker's, would require to have this formula doubled in order to introduce it.

Heddle's Haughtonite would be represented by the following series of formulae, that given first being represented *in extenso.*

Haughtonite of average composition:—

RATIO OF Ac, Si = 2 : 3.



Haughtonite with a maximum of monad metals:—

RATIO OF Ac : Si = (1 : 3) + 3 (2 : 3).

$$\mathrm{Ac}\left|\begin{array}{l}\mathrm{SiO_4Ha_3}\\ \mathrm{SiO_4Ha_3}\\ \mathrm{SiO_4Ha_3}\end{array}\right.,\quad \mathrm{Ac}\left|\begin{array}{l}\mathrm{SiO_4Ac}\\ \mathrm{SiO_4}\\ \mathrm{SiO_4}\end{array}\right\rangle \mathrm{Ms_3},\quad \mathrm{Ac}\left|\begin{array}{l}\mathrm{SiO_4Ac}\\ \mathrm{SiO_4}\,|\,\mathrm{Ms_2}\\ \mathrm{SiO_4}\,|\,(\mathrm{MsOHa})_2\end{array}\right.,\quad \mathrm{Ac}\left|\begin{array}{l}\mathrm{SiO_4Ac}\\ \mathrm{SiO_4(MsOHa)_3}\\ \mathrm{SiO_4Ha_3}\end{array}\right..$$

Haughtonite with a minimum of monad metals:—

RATIO OF Ac : Si = (2 : 3), (1 : 3), 2 × (3 : 3).

$$\mathrm{Ac}\left|\begin{array}{l}\mathrm{SiO_4Ac}\\ \mathrm{SiO_4}\\ \mathrm{SiO_4}\end{array}\right\rangle \mathrm{Ms_3},\quad \mathrm{Ac}\left|\begin{array}{l}\mathrm{SiO_4}\\ \mathrm{SiO_4}\\ \mathrm{SiO_4{-}Ms(MsOHa)}\end{array}\right\rangle \mathrm{Ms_3},\quad \mathrm{Ac}\left|\begin{array}{l}\mathrm{SiO_4Ac}\\ \mathrm{SiO_4Ac}\\ \mathrm{SiO_4Ha(MsOHa)_2}\end{array}\right.,\quad \mathrm{Ac}\left|\begin{array}{l}\mathrm{SiO_4Ac}\\ \mathrm{SiO_4Ac}\\ \mathrm{SiO_4Ha_3}\end{array}\right..$$

By combining so many atoms of Ha directly with silicon tetroxyl, this theory involves the existence of a larger number of non-hydrated molecules of magnesia and ferrous silicates, and thus leaves a larger margin for hydration to occur in weathering. The triradiate form of the molecule is quite

as consistent with the approximately hexagonal form of the mica as is the hexagonal shape of Tschermak's molecule.

A test as to the relative correctness of the two modes of viewing the subject might be furnished by the composition of the residual silica. What it should be on Tschermak's hypothesis I have already indicated; on Clarke's it would naturally be SiO_4H_4, which makes no nearer approach to the formula found by experiment, and indeed a little less than that suggested by Tschermak's formulæ.

A word must be added on the nomenclature of the species of biotite; excluding anomite there are left, according to Tschermak, meroxene and lepidomelane, which are distinguished by a difference in the ratio of the alkalies to the water present in each, the former characterized by the ratio (K, Na) : H = 3 : 3 the latter, by 2 : 4. The analyses discussed by Tschermak do not, however, bear out this distinction, as will be seen on referring to the reduced analyses Nos. 2 and 3, p. 24, of Tschermak's *Memoir*, which represent a meroxene with K : H, 2 : 5.

Perhaps a classification somewhat after the following may be provisionally adopted :—

- Biotite
  - Anomite.
  - Eunomite
    - Meroxene, Mg : Fe″ > 2 : 1.
    - Lepidomelane, Al : Fe‴ < 2 : 1.
    - Haughtonite, Mg : Fe″ < 2 : 1.
    - Siderophyllite, Ms = Fe″ (no magnesia).

MUSCOVITE.—Characters of particular interest are presented by this mineral. It generally occurs in idiomorphic six-sided plates with the silvery lustre and other optical properties of the species. In the granite of Three Rock Mountain these plates attain a considerable size, being on an average about 20 mm. in diameter; they contain numerous enclosures of biotite, which gives them a spotted appearance—a fact noticed by Dr. Haughton, who thought it might be peculiar to these examples; it proves, however, to be common to all or nearly all the primary muscovite of the Leinster granite, and is alike present in the small plates of the Poulmounty granite as in the larger ones of Three Rock. The inclosed

biotite scales lie with their flat faces parallel to those of the muscovite, through which they are scattered usually irregularly, but sometimes with a zonal arrangement, forming narrow bands parallel to the edges of the hexagonal muscovite crystals (fig. 4).

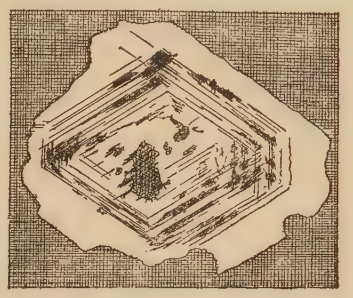


FIG. 4.

A crystal of muscovite, showing zonal arrangement of included biotite.

Under the microscope each patch of biotite is found to consist of several layers (cleavage laminæ), which extend to different distances into the surrounding muscovite, terminating in sharply-defined but exceedingly irregular margins. They have the unmistakable appearance of corroded fragments. That this is certainly their nature is shown by the abrupt truncation of the contained pleochroic aureoles (fig. 5). When these occur close to the margin, the central zircon of such an aureole may sometimes be seen lying half-immersed in the biotite and half in the muscovite, the aureole surrounding it within the biotite, but ceasing abruptly along its edge, not extending into the muscovite. In some cases (fig. 5 z), a crystal of zircon may be observed lying entirely within the muscovite near but outside the margin of a patch of biotite, which then presents a segment of an aureole, having the zircon for a centre—a fact which finds its readiest explanation in the corrosion of the biotite. Other observers have already described peculiarities in the association of biotite and muscovite, which led them to suppose that the latter mineral had been developed at the expense of the former; but the universality of biotite-spotting in the granite under consideration reveals a remarkable phase in the history of the consolidation of the rock, when the building up of biotite was succeeded by its decomposition, and

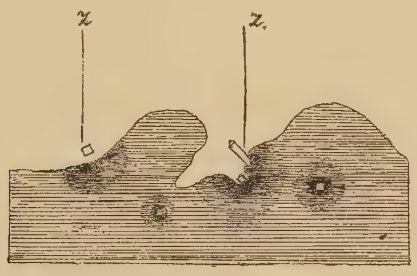


FIG. 5.

The corroded edge of a flake of residual biotite included in muscovite, seen under a Zeiss D. oe. 3.

subsequent re-formation as muscovite. In the Leinster granite, then, primary muscovite may be regarded as, to a great extent, the product of the action of the magma on the previously formed biotite.

Remarkably beautiful instances of zonal structure are presented by the Leinster muscovite. The large lozenge-shaped plates of Three Rock Mountain furnish the best examples, but the little flakes in the Poulmounty granite are scarcely inferior. To observe this feature all that is necessary is to peel off a cleavage lamina and to examine it under a low power of the microscope between crossed nicols, the plate being orientated at an angle of about 45° with its position of extinction; about a central hexagonal area, the sides of which correspond to the edges *b.m.*, are then seen a vast number of concentric hexagonal zones of different depth of tint, or of different colour according to the thickness of the lamina; their sides are defined by absolutely straight lines, and the angles are frequently true, but sometimes rounded off, owing to resorption: all extinguish simultaneously, and their distinction from each other probably depends on a difference in the value of $\gamma - \alpha$, due to slight differences in chemical composition.

The existence of these zones renders it easy to determine the position of the plane of the optic axes; it is, as already shown by Haughton, that of true muscovite, viz. parallel to the longer diagonal of the prism *m.*, or at right angles to the clinopinacoid *b.*: the value of the axial angle has been determined in air by Haughton for several examples of this mica.

The chemical composition of the muscovite has also been given by Dr. Haughton for four examples, and from the average we may calculate the probable existence of four molecules of ideally pure muscovite — $Si_6\ Al_6\ K_2H_4O_{24}$—in conjunction with one molecule of biotite of the following formula:—$Si_6O_6\,(OAcOH)_2(OMsO)_2(OHa)_4$. The angle of the optic axes is given as 53° 8′ for muscovite from Three Rock; 70° 4′ for that from Glendalough; 72° 18′ from Mount Leinster; 76° 15′ from Poulmounty. If we attempt to correlate the difference in value of this angle with differences in chemical composition, we find that they do not depend on the ratio of the potassium to the hydrogen present, nor on the proportion of iron found, though we can hardly make a satisfactory investigation

with regard to the latter component, since it is all given as peroxide, while it may possibly exist in part as protoxide; a very distinct relation, however, can be traced between the proportion of magnesia present and the value of the axial angle. Thus in the Three Rock mica as much as 1·13 °/₀ MgO occurs, in the Glendalough 0·9 °/₀, in that from Mount Leinster 0·72 °/₀, and in that from Poulmounty, which possesses the largest angle only 0·29 °/₀. Now the magnesia may be taken as the surest indication of the extent to which biotite rays enter into the composition of the muscovite molecule, and it will be seen that the magnitude of the angle varies inversely with the quantity of this constituent, and this is what we should theoretically expect.

Since the muscovite has been partly formed from the reconstruction of biotite material, and since residual fragments of biotite occur more abundantly in the middle than towards the edges of the muscovite crystals, we might also expect to find a difference in the axial angle in the centre, and nearer the margins of the muscovite plates, and this difference is found on measurement to actually exist. In one instance from Three Rock muscovite, I found an angle of 56° 45′ in the interior, and of 58° 40′ near the edge of a cleavage lamina, pointing to a decrease in biotite material on passing from centre to surface.

Dr. Haughton found a difference of 14° 30′ between different specimens of muscovite from the same locality (Haughton *loc. cit.* p. 596), and Tschermak records a similar difference between different laminæ of the same crystal of phlogopite, (Tschermak, *loc. cit.* p. 27), as well as a difference between the angle for the centre of a crystal of anomite and its margin; in the latter case the kernel is stated to be darker in tint than the border; the angle for the latter with red light is 12° 44′, for the kernel 16° (*loc. cit.* p. 26). These examples suggest a correspondence between the zonal structure in mica and differences in chemical composition, and so far support the view that the zonal structure of felspar has a similar significance.

SODA-LIME FELSPARS.—This series is well represented throughout the granite of the district, the species most abundantly present varying from

oligoclase to albite, in accordance with the chemical composition of the rock; from albitic oligoclase as a centre the series extends on the one hand up to albite, and on the other for a variable distance towards anorthite, this extremity of the series being reached in the case of some soda-granites.

When the constituents of a typical soda-granite are separated by means of heavy fluid, felspar begins to fall at a specific gravity of over 2·726, and continues from this up to 2·52. The heaviest fragments are associated with so much muscovite and other impurities that it was not thought worth while to attempt to prepare them for analysis; they were, however, examined under the microscope; good cleavage fragments were found, bounded on two opposite sides by planes corresponding probably to 001, and these extinguished at a maximum angle of 36°. This, taken in conjunction with their high specific gravity, would lead us to refer them to anorthite.

The heaviest felspar of which an analysis was made had a density of 2·721. Evidently it was not a pure gathering, as is shown by the following very unsatisfactory results:—

SiO_2,	53·54
TiO_2,	0·27
Al_2O_3,	36·28
CaO,	9·53
MgO,	0·35
Alkalies,	8·30 (by difference)
H_2O,	1·73 (by loss on ignition)
	100·00

It is probably a mixture of muscovite and felspar in the proportion, approximately, of one molecule of each.

More satisfactory results were obtained from the felspar which fell below 2·704, though the specific gravity appears to be too high, as will

be seen by its close correspondence in composition with lime-soda felspar of specific gravity 2·684.

	Felspar from Aughrim Granite, sp. gr. 2·704.	Calculated composition of Andesine, sp. gr. 2·684.
Silica, ...	57·04	57·37
Alumina, ...	27·69	27·12
Lime, ...	9·18	8·92
Alkalies, ...	4·59 { by difference.	6·59
Water, ...	1·17 { by loss on ignition.	

A determination of alkalies was made on a sample of specific gravity 2·683; it gave:—

Potash, ...	0·87
Soda, ...	6·83
Total, .	6·96

thus corresponding to Ab_2An_1 of specific gravity 2·671.

It will be seen that a small percentage of potash was found in felspar* of so high a specific gravity as 2·683; it was therefore of interest to determine the proportion present in the more alkaline members of the series. Great care was taken to obtain a pure separation of albite of sp. gr. 2·629, and this yielded 8·708 °/₀ of soda (Na_2O) and 1·741 °/₀ potash (K_2O). The lime was not determined, but was probably present to the extent of one or two per cent., judging from analogy with a similar felspar of sp. gr. 2·628 from the Three Rock granite which gave on analysis the following:—

Silica, ...	67·17
Alumina, ...	20·50
Ferric oxide, ...	0·22
Lime, ...	1·61
Magnesia, ...	trace
Soda, ...	10·16
Potash, ...	0·65
Water, ...	0·31
Total, ...	100·62

* Probably due to included Secondary muscovite.

Another gathering of albite from the Aughrim granite of sp. gr. 2·615 was found to contain 12·289 °/₀ of alkalies, of which 4·205 °/₀ is potash, and 8·084 °/₀ soda. This corresponds approximately to the formula Ab_3Or_1, the theoretical specific gravity of which is 2·606, probably the presence of a small quantity of lime not determined will account for the difference between this and the actual specific gravity given above.

Excluding the albite from Three Rock, the felspars under description were obtained from Aughrim soda granite, in which the soda-lime felspars all present the zonal charaeter. The fragments of these felspars separated by heavy fluid still retain the zonal structure, as is easily seen when they are examined under the microscope, and it is possible, therefore, that our analyses are made not of single felspar species, but of collections of zoned fragments having the same average density; at the same time the important result remains that these zonal fragments by their density and chemical composition can be arranged in a series which at one end approaches the more basic labradorite and terminates at the other in a potash-bearing albite.

The boundary of the plagioclase felspar varies from idiomorphic to hypidiomorphic, the forms commonly present in the former case being (001), (010), (110), (110); when additional faces occur they appear, so far as can be deduced from a study of thin slices of rock, to be (201).

Simple twinning of the Carlsbad, and sometimes of the Baveno type, and synthetic twinning on the albite and pericline plans are the rule rather than the exception.

Zonal structure exquisitely perfect, characterizes much of the plagioclase (fig. 6), a dyke of minutely porphyritic microgranite near Aughrim affording the best examples in felspar which is so fresh, colourless, and transparent in section that one may fairly speak of it as displaying the microtin habit, not apparently a very common feature in a pre-carboniferous rock. This, however, is exceptional, and more usually these felspars are rendered dusty, granular or opaque by the presence of decomposition products, which are most abundantly developed in the middle of the crystals, the outer margin generally remaining more or less clear.

The growth of the felspar crystals, as recorded in the form of the

zonal envelopes, was evidently far from uniform or continuous; the relative size of the different faces was subject to gradual change, some faces growing smaller eventually disappeared, and others starting into existence as very insignificant features finally acquired considerable importance, so that the form of the completed crystal is not always that with which it started. Frequently also all the angles between adjacent faces become rounded off, showing that during a short interval of unknown duration the growth of the crystal was interrupted, and deposition gave place to solution of previously formed material.

FIG. 6.

An individual of zonal felspar in Aughrim Granite, broken and recemented by fresh growth.

The zonal structure may be observed in ordinary light, owing to a slight difference in the refractive indices of the successive zones; but it is only between crossed nicols that it becomes manifest in all its beauty. If under these conditions we determine the angle of extinction of the several zones we shall find that this differs greatly for different zones; in a rectangular section, bounded by 010, 001, the outermost zone will frequently be found to extinguish at an angle of 14°. The angle diminishes as we proceed towards the centre, till it becomes zero; up to this point we may speak of the angle as positive; beyond it, as the crystal is rotated, the angle of extinction increases towards the centre, till it may reach or exceed 24°. This extinction on this side of zero we may distinguish as negative. If the difference in the angle of extinction can be correlated with differences in chemical composition, the results of our chemical investigation will be found to be in very close agreement with those deducible from an optical examination; for, to take the angles just mentioned as typical, we find that an extinction of 15° in a plane perpendicular to *pg′* indicates a felspar nearly allied to albite, and one of 24°, another midway between andesine and labradorite, and thus, united together in the same crystal, building it up by successive envelopes, we should have representatives of all the felspars which we have

discovered in the rock; and, as on *à priori* grounds we might have expected, the more basic felspar would have been found occupying the interior of the crystal, the envelopes as they approach the exterior assuming a continually more acid character.

It is doubtful, however, whether this explanation can be adopted in its entirety. Michel Levy has shown that in certain cases all the phenomena of zones can be satisfactorily explained on the assumption of an ultramicroscopic twinning after the albite and pericline plans. In association with M. Fouqué he has observed in the artificial production of felspar that the elementary microliths of which the large crystals are built up are elongated parallel to the edge 001, 010, and arrange themselves in parallel bundles also elongated in the same direction. We have then only to conceive that some of these are oriented in one direction, and others by a rotation of 180° round an axis perpendicular to 010 in the opposite direction, to understand how the zonal structure may result.

M. Levy distinguishes three cases in the behaviour of sections of zonal felspar when examined between crossed nicols:—

1. The concentric bands and lamellar twins of the albite type simultaneously disappear, and the section appears homogeneous and equally illuminated four times in the course of a complete rotation between crossed nicols. In this case the banding is to be attributed to microlithic hemitropy.

2. The effacement of the banding is not coincident with that of the lamellar twinning. This involves the absence of microlithic hemitropy, and a study of extinction angles proves the presence of two bodies optically different, of which the second does not identify itself with the lamellar hemitropes.

3. The concentric banding is never completely effaced at any angle of rotation. This—a somewhat rare case—involves the existence of at least two bodies of different composition and their hemitrope reversals.

Examples of all these three cases may be met with in the zonal felspar of the Leinster granite; they may be found in a single rock slice, but the first of them is by far the commonest: of the second occasional instances occur, but the third is rarely met with. An instance of the

second case is presented by a section, which a single lamellar twin traverses from end to end, and when the outer zone is extinguished the greater part of the middle of the lamella becomes extinguished also. Similarly the median zone, which lies between the outer one and the centre, extinguishes simultaneously with the outer ends of the lamella. This would indicate, according to M. Levy, that the greater part of the section (all but the middle area) is composed of the same species of felspar (oligoclase, judging from the angle of extinction), the optical orientation of which is reversed on passing from the middle to the outer zone: the extinction angle of the central area only differs by 6° from that of the middle zone, being 16°, while that of the latter is 10°. Thus, while according to Hoffner's hypothesis we should regard this crystal as consisting of oligoclase or andesine in the centre, and of progressively more albite-like felspars towards the exterior, till albite itself was closely approached, on Levy's theory we should regard it as consisting chiefly of one kind of felspar, probably oligoclase, with only a slightly more calcareous component in the centre. It may be mentioned as confirmatory of Levy's explanation that in many zonal felspars when hemitrope lamellæ on both the albite and pericline plans are present in the same crystal it will be found that these each lie parallel to a margin of the zones, showing that the outline of the zones is to a great extent parallel with the albitic and pericline directions in which the hemitrope microliths are supposed to lie.

There is nothing inconsistent between this explanation and the results we have obtained by other methods of examination; thus, by means of a diffusion column we find that the specific gravity of the great bulk of the plagioclase felspar in a soda-granite lies between 2·635 and 2·65, so that it includes those varieties of oligoclase in which the proportion of albite (Ab) to anorthite (An) varies from $Ab_{12}An_1$ to Ab_4An_1, and the extinction angles corresponding to these agree very well with those obtained from an examination of thin slices. At the same time these results are equally consistent with Hoffner's explanation. I had hoped to bring the rival theories to a crucial test by the optical examination of the separated fragments of the different felspars: in a rock-slice it will be frequently observed that the core of the felspars is granular, and more or less opaque, owing to the

development of decomposition products, while the exterior is comparatively clear and homogeneous. If, then, there exist any great difference in composition between the exterior and the core we should find on breaking up the crystals and separating them according to their specific gravity, that the heavier fragments included most "cores," and the lighter most "borders"; and certainly experiment to a certain extent confirms this expectation, for the fragments of highest specific gravity consist nearly altogether of cores, and transparent fragments certainly increase in quantity as the specific gravity falls, but at the same time granular cores are present in considerable numbers in all the separations, thus showing that the centres of the crystals are not always of a comparatively high basic character, as on Hoffner's theory we should expect, but that they vary from the most basic to the most acidic species present in the rock, *i. e.* that the increase in acidity among the felspars was not altogether brought about by a change in the character of the successive envelopes of similar crystals, but also by the appearance of successive crops of different varieties of felspar individuals: at the same time Hoffner's explanation holds good to a certain extent, as explaining slight differences in felspars belonging to Levy's second case, and perhaps also the general increase in the proportion of transparent fragments to opaque cores as the specific gravity of the collected fragments of crystals diminishes. It is also supported by the facts that the outlines of the zones can be seen without the aid of polarised light.

MICROCLINE.—This felspar, which had been originally confounded with orthoclase, was first rightly identified by Prof. O'Reilly, who draws particular attention to the remarkable freshness of its appearance as compared with the other species of felspar, which are generally more or less altered by kaolinisation, or the development of secondary muscovite.

In some cases microcline is the most conspicuous felspar present in the granite, occurring as porphyritic crystals of considerable size, one or two inches, or even more in length; it then, as it does sometimes when not markedly exceeding the other felspar crystals in size, exhibits more or less idiomorphic outlines, which may be maintained even against quartz when this forms part of its boundary. In such cases, which are rare,

the consolidation of microcline was evidently anterior to that of quartz. In rare instances grains of quartz have been observed as inclusions, lying right in the very middle of the felspar. Idiomorphic outlines are the exception, allotriomorphic boundaries the rule, and the microcline which has generally been the last constituent to crystallize out, occurs filling up the interspaces left between the other constituents of the rock. In fig. 7 it is represented filling up cracks in quartz, some of which have every appearance of having been formed after consolidation.

FIG. 7.
Microcline in quartz.

A structure of great interest as proving that the excretion of microcline has in some instances been subsequent to the formation of micropegmatite is shown in fig. 8. Most centrally situated is a crystal of felspar, which is completed marginally by a micropegmatitic intergrowth with quartz, the quartz occurring in curved branching fibres which start from one face of the quartz free felspar core: the pegmatitic border terminates in a somewhat mammillary surface, and modelled upon this is seen an adjacent crystal of microperthite.

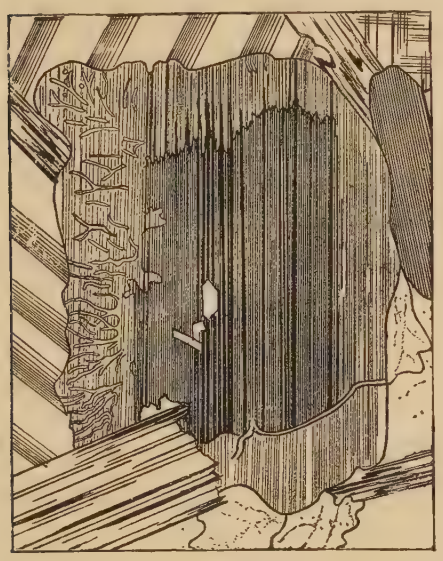


FIG. 8.
Micropegmatitic border to a crystal of oligoclase.

Some of the large porphyritic crystals of microcline were analyzed by Prof. Galbraith, and specimens of these crystals, or of similar ones from the same localities as those chosen by Prof. Galbraith are preserved in the Museum of Trinity College. Of these I have had thin slices prepared taken parallel to the two chief cleavages. Crystals from Dalkey show the

characteristic lattice twinning very uniformly developed on the *P* face, and the usual extinction angle of 15°; on the face *M* the basal cleavage planes are the most conspicuous features; the extinction angle measured against these is 4° 30′; in both sections a few grains of included quartz are visible, and a good deal of other felspar is present, partly as an intergrowth—in this case the second felspar is albite—and partly as scattered corroded idiomorphic crystals, with synthetic twinning; these do not often extinguish symmetrically, frequently 3° would be measured on one side of the twinning face, and 12° on the other; in one instance a near approach to symmetric extinction gave 18°·30′ on one side, and 17°·30′ on the other. This, taken in conjunction with the fact that Galbraith's analysis shows the absence of lime, proves that the included crystals are also albite. The intergrown albite runs along lines in irregular threads, which on the face *P* make an angle very frequently of 34° with each other; on *M* they run transversely to the basal cleavage, but approximately parallel with that of the irregular prismatic cleavage.

From Galbraith's analysis we find, on computation, that the microcline complex consists approximately of 75°/₀ of orthoclase and 25°/₀ of albite, or $Or_{2\cdot8}\ Ab_1$; and it would appear from the microscopical examination that the whole of the albite is present in the included crystals and intergrowths, and hence that the microcline proper consists wholly of potash felspar.

In an examination of carefully separated microcline of specific gravity 2·57 from Three Rock Mountain, I found 12·146°/₀ of potash and 3·6915°/₀ of soda, from which we find by calculation 71·74°/₀ of orthoclase and 31·18°/₀ of albite. This is 2·92°/₀ too much of total felspar, so that one or both the alkalies was found in excess; if the fault lay with the soda alone the amount found should have been 3·346 instead of 3·6915°/₀. With the latter number we obtain the ratio $Or_{2\cdot16}Ab_1$, with the former $Or_{2\cdot36}Ab_1$; in either case the result is curious, considered in relation to that obtained from a consideration of the Dalkey felspar. It might be worth while separating, if possible, the albite from the microcline of the Dalkey crystals, to determine whether they possess the purity conjectured; if so, the difference is possibly to be explained by the fact that the microcline of my analysis

occupies an interstitial position in the granite, while that of Dalkey occurs as large crystals.

Crystals of microcline from Glendalough, cut parallel to *P*, do not show the usual rectangular lattice structure; in its stead there appears a curious irregular wedge-like intergrowth—the wedges extinguishing with the usual microcline angle. On *M* a similar tendency to wedge structure is observable; in addition to quartz a little muscovite is present, partly primary, partly secondary; the intergrown albite forms broad bands, with well developed synthetic twinning. Synthetic twinning also occurs in the similar albite of the Dalkey crystals, and the twinning planes in that case appear to coincide in direction with one set of the twinning planes of the microcline.

A crystal from Lough Dan, examined parallel to *M*, very much resembled those just described; the intergrown albite, however, does not present lamellar twinning; on the *P* plane the crystal proved to be composite, and one of its components presented a remarkable appearance. It is twinned in very regular lamellæ, which, however, are all very uniformly curved into a circular arc: extinction is undulose. The feature is possibly a distortion, due to pressure developed during the crust movements which have given a gneissose character to so much of the granite of the neighbourhood.

ORTHOCLASE.—This is absent in much of the granite of the district, microcline usually taking its place. When both felspars occur together, the orthoclase is usually idiomorphic, giving rectangular and hexagonal sections, with Carlsbad twinning. Its specific gravity varies from between 2·57 to 2·517, and in consequence it is exceedingly difficult to separate from microcline; indeed this can only be accomplished by repeatedly separating the lightest examples of orthoclase from the heaviest of microcline. In this way I have separated microcline for analysis, but no analysis has been made of the orthoclase.

In those examples of granite which do not contain any microcline the orthoclase is frequently allotriomorphic (as in that from Ballaghkeen).

QUARTZ.—This is of the usual granitic character, occurring in large allotriomorphic grains, traversed by cracks and planes of vapour cavities. It is remarkably free from inclusions, though all the preceding constituents are occasionally enclosed by it. It appears sometimes to have exercised a solvent action on some of its predecessors; thus, groups of zircon and apatite, when they occur in it, usually lie near to corroded flakes of biotite, as though they had been left as insoluble residues after the removal of biotite, in which we may presume they were originally included. It is difficult to understand, however, if this explanation be correct, what has become of the dissolved material. It certainly has not given rise to fresh minerals by its interaction with the silica of the quartz; and one must suppose that it became dissipated by diffusion before the consolidation of the quartz took place.

Besides its occurrence in the form of grains, quartz is very commonly found intergrown with orthoclase, albite, or microcline in pegmatitic fashion (fig. 9). It then simulates, with an extraordinary degree of resemblance, the canal-system of Eozoon; and it seems to me not at all impossible that the resemblance is, so to speak, real, *i.e.* that the characters of the Eozoon canal-system, so called, are the result of the simultaneous crystallization of calcite and an ophitic mineral. This supposition is to some extent supported by the fact that I have been able to produce artificially a canal-system which is as similar to that of Eozoon as it is to micropegmatite; and, thus, although I cannot claim to have manufactured "graphic granite," a proceeding which Dr. Carpenter seemed to suggest was necessary to the establishment of its inorganic nature—"When a petrologist has succeeded in making a graphic granite, he will be entitled to speak with assurance of its purely mineral nature" —(*Nature*, vol. XIV., p. 76, 1876)—yet I have obtained a very colourable

FIG. 9.

Quartz intergrown with microcline.

imitation of it. The process is a very simple one—take a small quantity of jelly made by warming gelatine with water, freeze it, and then cut thin slices in the freezing microtome, mount these in glycerine, and the canal-system will be beautifully displayed, fig. 10. In my experiment a fragment of a sponge, which had been preserved in alcohol, was embedded in the jelly before slicing, and the canals were observed to start from the surface where the jelly met the organism. It is possible that for good results some such surface should be provided for the origin of the canals; this is a point I have not investigated. The canals are no doubt due to the simultaneous freezing of water and the jelly (an indefinite mixture or union of gelatine and water, and an excess of water, which probably took the form of ice spicules); on thawing, we may presume that the spaces left by the ice spicules assumed the character of water-filled canals. It is possible that the subject is deserving of more attention than I have yet been able to devote to it.

FIG. 10.

Canals made by freezing jelly.

General Structure.

GRANITITE.—Rosenbusch proposes to restrict the term granite in an exact sense to such members of the family as contain white mica as well as black, while to those in which primary muscovite is absent and a dark mica alone present he applies the name "Granitite." This he regards as the more abundant rock of the two, but in the Leinster district this is not the case, the main chain, seventy miles in length, with an average width of eight or ten miles, and a maximum in one part of eighteen (Jukes and Haughton, 16), consists of genuine granite, and muscovite as well as biotite is present in all the outlying exposures except two; these are Carnsore and Ballynamuddagh: in these localities muscovite fails, and the rock, according to Rosenbusch's view, must be regarded

as granitite. It is a point of some interest that these localities are of all the outlying masses the most remote from the main chain; Carnsore is the farthest off of all, and Ballynamuddagh lies midway between it and the great mass. The description of the Ballynamuddagh rock will be given first.

Granitite of Ballynamuddagh.—(CaO, 3·85; Na_2O, 3·36; K_2O, 2·73, Haughton). According to Dr. Haughton's analysis this contains a larger proportion of lime than any of the other granites of Leinster, as will be seen by reference to the percentage of this constituent given along with the alkalies, in brackets, immediately after the name of the locality, in this and succeeding instances.

Biotite occurs in well-formed hexagonal prisms, and in ragged corroded fragments, some of which are situated within the core of the felspar crystals, and some within quartz: in the latter case the biotite is frequently present as small hexagonal plates and thin, round, or elliptical discs, about 0·02 by 0·01 mm. in diameter. The larger crystals of biotite are sometimes invaded by felspar or quartz which have eaten their way into it in well defined patches of irregular outline; this corrosion appears to be accompanied by the simultaneous excretion of magnetite, which frequently occurs as a row of granules margining the invader. The cleavage planes are frequently more or less curved as a consequence of deformation resulting from earth movements (pressure metamorphism). The colour is bright reddish-brown, as seen through the cleavage faces; the dichroism is intense, sections at right angles to the cleavage planes appearing a faint yellowish brown for ordinary rays, and a deep reddish-brown with extraordinary. Occasionally, a little almost colourless or bleached biotite, may be observed: this, however, still retains an intense dichroism.

Zircon and apatite occur in the usual association with biotite: both are of unusually large dimensions. The apatite presents zonal structure; its core is finely granular and dichroic; its exterior margin clear and colourless. Some of the zircon crystals measure 0·2 by 0·06 mm.

An extensive resorption of biotite, without the formation of muscovite as a secondary product has occurred in this rock. The evidence of resorption is of the clearest nature. Starting from well-preserved crystals of biotite,

with their included zircons and apatite as one end of the series, we can trace these into a stage where half the biotite of a crystal has disappeared, its place being taken by felspar, while the zircons and apatite set free by solution remain in place as a nassociated group which would be included within such a line as the remaining outlines of the biotite would enable us to draw if we attempted a restoration. From this we pass to a stage in which fragments of biotite and associated crystals of apatite, or zircon, or both, lie scattered together in the subsequently formed mineral; and finally we reach the stage which closes the series, when a few apatite crystals, with or without zircons occur alone in the midst of a felspar to mark the place previously occupied by biotite, which has now entirely disappeared.

An examination of the biotite for alkalies gave the following results:—

Potash (K_2O), - - - -	8·227
Soda (Na_2O), - - - -	1·645
Total, - - - -	9·872°/₀

This determination was made with the intention of obtaining data for calculating the mineralogical composition of the rock by simultaneous equations, but this intention was soon abandoned because the presence of magnetite, zircons, apatite, some sphene, of bleached and chloritised biotite, kaolinised felspar, and felspar molecules of three kinds, albite, anorthite, and orthoclase, rendered the problem too complicated for any but a very approximate solution which could be obtained more easily by other means. Before proceeding to notice the felspars we may briefly investigate this question, attempting first to discover the minimum proportion of anorthite probably present. It has been stated above that Dr. Haughton's analysis indicated the presence of 3·85°/₀ of lime; but not the whole of this can be referred to anorthite: a part is combined with phosphoric acid as apatite. In the Aughrim soda-granite, as will be seen later, 0·3°/₀ of apatite is present, containing 0·162°/₀ of lime; this deducted from 3·85, the total quantity found, leaves 3·688°/₀: but of this again a part must be referred to biotite and sphene; neglecting the latter, because some of it probably comes to be analyzed along with the biotite, we may consider

the biotite alone. In the Aughrim granite, biotite is present to the extent of about 7°/₀; a generous allowance for the present case will be 10°/₀, and from my analysis of the Aughrim biotite we may regard 2·03°/₀ of this as lime. We must, therefore, deduct a further quantity of 0·203 from the remainder 3·688 already found; this gives 3·485°/₀ of lime to be accounted for, and if the whole of this goes to form anorthite, as seems inevitable, then of this felspar there will be present 17°/₀.

We now pass to the soda, of which 3·36°/₀ is shown to be present by Dr. Haughton's analysis; deducting 0·165 as the share for biotite, there is left 3·2°/₀, representing 27·1°/₀ of albite. Finally, of potash only 2·78°/₀ occurs in the rock, and from this 0·823 must be deducted on account of the biotite, leaving 1·96°/₀ equivalent to 11·6°/₀ of orthoclase.

The relative number of molecules of each felspar is, therefore, as follows: of orthoclase 208; albite, 515; anorthite, 305; or, roughly speaking, $Or_2Ab_5An_3$.

Most of the orthoclase molecules are no doubt sorted out from the other two kinds, and mainly contribute to the substance of the orthoclase individuals, which a study of thin slices shows to be present in the rock, to the entire exclusion of microcline, otherwise so common in the Leinster granites. Passing from this to the albite and anorthite molecules, we find that these, so far from being collected together to form a single species of felspar, are distributed in a great number of different combinations, ranging from albite, probably containing some orthoclase molecules at one end of the series, to at least as far as labradorite at the other, with a slight preponderance of andesine of the formulæ Ab_2An_1 and Ab_3An_1. This is very clearly shown by observations on a diffusion column; in this we find orthoclase of specific gravity 2·57, and less, forming the highest zone; below this succeeds a continuous scattering of felspar grains without any evident concentration into a zone till quartz is reached, when a dense clearly-defined zone of this mineral, possibly mingled with oligoclase (Ab_4An_1) is reached. Sparsely strewn grains of felspar occur below this, and two thin zones of specific gravity 2·67 and 2·68, the constituent grains of which evidently closely approximate to the composition Ab_2An_1, and Ab_3An_2; a few scattered grains continue the series till the index mineral

calcite (sp. gr. 2·715) is reached; about this a cluster of grains occurs indicating the presence of labradorite of the formula Ab_1An_2, ; lower than this only a few occasional grains, to which no importance can be attached, are met with.

The results of these observations find their confirmation in an examination of thin slices of the rock. The plagioclase felspar occurs in hypidiomorphic crystals, the margins frequently rendered irregular either by the interference of other plagioclase crystals or by passing into a microlithic or granulitic intergrowth of quartz and felspar—these minerals forming a fine-grained mosaic surrounding the pure felspar. Zonal structure is the rule, accompanied to a greater or less extent by lamellar twinning on the albite plan—more rarely that of pericline—the twinning in some cases affecting the whole crystal, in others only a portion, sometimes present in the middle but disappearing on approaching the margin.

Many of the zonal crystals include a number of scattered smaller individuals which always possess lamellar twinning, sometimes also zonal structure, and lie strewn through the host without regularity; sometimes definitely oriented, the twinning trace lying parallel to the edges *p*, *m*, and *g*, or sometimes not.

A study of the structure of the zonal felspars reveals an eventful history, in which growth was frequently interrupted by fracture or corrosion. The zonal outlines, though sometimes sharply polygonal, are more usually well rounded off, sometimes exceedingly irregular and ragged, while occasionally the zoned felspar is broken across, the portions separated from each other and cemented together by non-zonal felspar. Sections in the zone *pg'*, not uncommonly extinguish at 0°, at right angles to this zone at as much as 23° to 25°; these angles indicate oligoclase and andesine.

The felspar has evidently been affected by dynamo-metamorphism, as is shown by the occasional occurrence of bent edges and curved twinning planes.

Quartz is present in three forms—chiefly as large granitic grains, partly as small grains forming with felspar a fine mosaic, and partly as contributing to a micropegmatitic growth which may be observed extending in rounded lobate processes from a twinned zonal felspar, the growth of which it com-

pletes; while entirely surrounding both the micropegmatite and the felspar, from which it proceeds, occurs a second non-zonal felspar—presumably orthoclase—the outer margin of which is allotriomorphic to the other constituents of the rock including quartz.

The large grains are dusty with fluid cavities and contained minerals, including minute flakes and discs of biotite. The planes of fluid cavities extend in curved lines continuously across several grains—a single plane has been traced through no less than five individuals—and they are not always confined to the quartz; in one instance a plane was seen to cut across a crystal of biotite, one of felspar, and two of quartz. This is probably the result of comparatively slight pressure or dynamo-metamorphic action which is also suggested by the slight undulose extinction characteristic of some of the grains.

There is a singular paucity of sphene in this rock, but large crystals of zircon are present. The chief distinctive characters of the rock are the absence of muscovite and microcline and the presence of a more than usually high proportion of calcareous plagioclase.

GRANITE OF CARNSORE (CaO, 2·12 %; Na_2O, 3·06 %; K_2O, 4·77 % (Haughton)).—This is a coarsely crystallised rock of a reddish tint, rendered porphyritic by crystals of microcline, which are often twinned on the Carlsbad type. Biotite occurs in greatly corroded crystals, and in residual patches and films enclosed in felspar and quartz; zircons are numerous, apatite fairly abundant, and there is a considerable quantity of a black opaque mineral which looks like magnetite, but which must contain a considerable large percentage of titanium, if one may judge from the wide margin of sphene which frequently surrounds it. Primary muscovite is wholly absent; secondary muscovite occurs in very small crystals as a result of the alteration of felspar.

Plagioclase felspar occurs in more or less idiomorphic crystals, with fine lamellar twinning on the albite plan; some large rectangular sections, cut probably nearly at right angles to the zone *pg′*, extinguish almost symmetrically at an angle of 6°·30′ measured against the twinning trace; it is impossible to say whether this angle is to be regarded as negative or positive, but in

either case it indicates a felspar intermediate between albite and oligoclase. Some small lamellar twins, included within microcline, gave an angle of 17°30′. As these also are rectangular sections, this would point to albite. Traces of zonal structure occur in the larger crystals of plagioclase, but the difference in the angle of extinction for the centre and margin is not large.

Microcline occurs in large crystals of the usual character; in a section of one, albite was observed intergrown partly in narrow undulating veins, but partly also in narrow bands zonally situated, *i. e.* parallel to the faces *mm′*. Owing to the great difference in the extinction angles of albite and microcline when observed in the same section, the contrast between the albite zones and the rest of the felspar is very marked, and yet at four positions on rotation the two were so equally illuminated that to my eye no difference could be detected between them; this is clear proof that Levy's theory of zoning is not always borne out by observations on equal illumination.

If from the 2·12 °/₀ of lime found by Dr. Haughton's analysis we deduct 0·162°/₀ for apatite, and 0·203 for biotite, there remain 1·755 °/₀ available for anorthite, of which accordingly 8·8 °/₀ may be regarded as present in the rock; similarly from the total percentage of soda (3·06) we deduct 0·165 for biotite, leaving 2·895 °/₀ for albite, of which, therefore, 24·4 °/₀ is present, and from the potash (4·77 °/₀) we deduct 0·823 for biotite, leaving 3·947 for orthoclase, of which 23·3 °/₀ is, therefore, present; reducing these percentages to ratios of molecules we have of orthoclase 412, of albite 483, and of anorthite 122, or, approximately, $Or_7Ab_8An_2$. If all the albite and anorthite occurred together in a uniform mixture this would be an oligoclase of the formula $Ab_4\ An_1$. The occurrence of albite as shown by an examination of thin slices shows, however, here, as elsewhere, that this uniform distribution does not occur; observations with a diffusion column give confirmatory evidence. Thus a dense zone of microcline of specific gravity 2·57 floats highest, then follow scattered grains of heavier felspar, continuously extending down to quartz, and tending to form a zone at a level corresponding to specific gravity 2·64; below quartz only a very few isolated grains occur. It may be inferred that in addition to potash-microcline, soda-microcline is present, and probably potash-albite, as well as normal; there is evidently a small quantity of oligoclase of formula

Ab_8An_1. Quartz is present in large grains of the usual granitic character; it is dusty with mineral residues and traversed by numerous planes of liquid or vapour cavities, many of comparatively large size, with contained bubbles. A remarkable feature is the presence of fine striæ which traverse many of the grains; these are visible in ordinary light as delicate parallel scratches, such as might be produced in grinding down or polishing the rock-slice, but that this is not their origin would seem to be shown from the fact that between crossed nicols they are found to correspond to a banded appearance, which is very plainly visible when the grain is close to its position of extinction; the entire section of the quartz grain then seems to consist of somewhat lenticular elongated areas of slightly different tints alternately arranged, the general appearance recalling in some faint degree the perthitic structure in felspar. No one after a careful examination of this could doubt that the striation is the expression of a structural arrangement in the quartz; in the next place it frequently happens that the striation runs parallel to some of the planes of included liquid cavities, though it is crossed by others which do not make any constant angle with it; this would seem to point to some connection between the planes of included cavities and the striation, a suggestion which is supported by the fact that in the case of one very definitely expressed cavity-plane having a curved surface, a broad band similar to those just mentioned, was observed margining it, with an extinction slightly different to that of the rest of the grain.*

* Since this was written, I have received a copy of the remarkably interesting Paper by Professor Judd, "On the Development of a Lamellar Structure in Quartz by Mechanical Means." [Mineralogical Magazine, vol. viii., pl. I., 1888.] In this a quite similar structure to that just described is shown to exist in a large crystal of quartz which had suffered mechanical deformation: this and the lammelation both resulting from mechanical pressure. Professor Judd made an unsuccessful search for similar lammellation in the quartz grains of igneous rocks; it is therefore with peculiar satisfaction that I find the Leinster granite supplying just the evidence which Professor Judd looked for to complete his argument.

SODA GRANITE OF AUGHRIM.—A detailed account of this granite has already been published by me (27). It possesses a typical granitic structure, and like most soda-granites is of a white colour. Its specific gravity as determined by immersion in heavy fluid is 2·68.

An analysis gave the following results :—

Silica, - - -	70·69	(including some titanic acid.)
Alumina, - - -	15·20	
Ferric oxide, - -	3·76	
Lime, - - -	3·31	
Magnesia, - - -	0·45	
Potash, - - -	2·31	
Soda, - - -	4·69	
Water, - - -	0·56	(by loss on ignition.)
Total, - -	101·07	

The state of the iron in the rock was not determined, but as the greater part is contained in the biotite, and some in magnetite, there can be no doubt that by far the larger portion is in the ferrous condition: if the whole existed as ferrous iron it would reduce the sum total of the analysis to 100·69.

An attempt was made to determine the mineral composition by weighing camera lucida sketches of the sections of the minerals seen in thin slices under the microscope; as much as possible of the whole area of a slice measuring about 20 mm. square was sketched, and the tracings transferred to tinfoil. This was then cut up following the boundaries of the minerals; the pieces representing similar minerals were collected together, and after drying at 100° C. weighed on a precision balance. The sketches on paper were preserved for reference; they filled the field of the microscope twenty-four times, and in weighing the tinfoil tracings, the cuttings from six fields were weighed together, taken in the order in which they were drawn, the rock-slice being moved by a mechanical stage in definite

directions; the weighings therefore were obtained in four groups; reduced to percentages they gave the following:—

	Group 1.	Group 2.	Group 3.	Group 4.	Mean.
Sphene and epidote,	0·084	0·654	0·165	0·765	0·417
Primary mica, -	2·943	9·285	5·687	7·362	6·319
Zonal felspar, -	59·326	46·095	55·284	45·668	51·593
Microcline, -	7·206	10·692	12·488	8·014	9·600
Quartz, - -	30·441	33·274	26·376	38·191	32·070

From this it is evident that an area certainly not less than that sketched in this case should be employed when the mineral composition is to be determined by this method, but that with this quantity a very fair approach to an average may be obtained is suggested by the fact that the extremes exceed and fall short of the mean by very similar amounts, thus—

	Primary Mica.	Zonal Felspar.	Microcline.	Quartz.
Excess, -	2·966	7·733	2·888	6·121
Defect, -	3·376	5·925	2·394	5·694

The values, so far obtained, represent the volumes of the several minerals present. To obtain the weights, we must multiply the volumes by the respective specific gravities; this, of course, introduces a source of error, since the average specific gravity can only be estimated, and not exactly determined. The multipliers I have used will be seen in the following table—

Sphene and epidote, -	0·417 × 3·5	=	1·460	or	0·546	°/₀
Primary mica, - -	6·319 × 3·1	=	19·589	or	7·328	,,
Zonal felspar, - -	51·593 × 2·65	=	136·721	or	51·143	,,
Microcline, - -	9·600 × 2·56	=	24·576	or	9·193	,,
Quartz, - - -	32·070 × 2·65	=	84·935	or	31·790	,,
Total, - -			267·330		100·000	

If the total in the third column of figures be divided by 100 it will give the specific gravity which the rock should possess, if the assumptions we have introduced are correct. The actual specific gravity, as found by floating in a heavy fluid, is 2·68.

The numbers given in the fourth column represent the mineral composition of the rock by weight per cent. They differ in some of the decimal places from those previously given in my preliminary account, owing to slight differences in the value of the multipliers used in the two cases.

We may now proceed to calculate the proportions of the different felspars present from a consideration of the chemical composition of the rock as determined by analysis.

From the total percentage of lime (3·31 °/₀) we deduct 0·162 on account of apatite, 0·066 on account of the lime present in the biotite above that required to combine with the phosphoric acid found in this mineral, and finally 0·152 on account of the lime present in the sphene; after these reductions 2·930 °/₀ of lime remains. From the total quantity of potash (2·31 °/₀) we deduct 0·522 on account of biotite, leaving 1·788 °/₀; it will be observed that with biotite we include the small quantity of primary muscovite present in the rock, but of the secondary muscovite no notice is taken: this must of course affect our results to some indeterminable extent. From the soda (4·69°/₀) we deduct 0·207 on account of biotite, leaving 4·483°/₀. Tabulating our results, we have as follows:—

Potash felspar (Or.),	-	10·56 °/₀	equivalent to	1897	molecules.
Soda felspar (Ab.),	-	37·86 ,,	,,	7217	,,
Lime felspar (An.),	-	14·56 ,,	,,	2014	,,
Total,	- -	62·98			

The total felspar thus obtained differs only by 1·8 from that got by the weighing of sketches. So close an approximation may give us confidence in our results, so that we may use them as a basis for further argument. Thus it will be seen that the value for potash felspar, found above (10·56°/₀), differs from that previously obtained for microcline by only 1°/₀; and, consequently, if all the potash felspar were collected together in pure crystals, all but 1 °/₀ of these would nave the characters of microcline, the remaining 1 °/₀ those of orthoclase. More probably, however, this surplus 1 °/₀ represents an excess in our estimate owing to our having disregarded the difference between the potash contents of the biotite and muscovite in

calculating both together as though they were biotite. I cannot assert the presence of orthoclase in the granite, although I have given it a very careful microscopic examination, and consequently I believe that the only potash felspar present in individual crystals is microcline. It may be observed that the microcline is not a pure potash felspar, since it contains a considerable quantity of soda, but on the other hand the soda-lime felspars contain a considerable quantity of potash. Thus, the distinction we made at first between the idiomorphic zonal felspar and microcline corresponds to the distinction between soda-lime and potash felspar, though the first contains some potash and the latter some soda.

Reverting to the last table in which the relative number of felspar molecules is given, it will be seen that they give the formula $Or_1Ab_{3\cdot8}$ $An_{1\cdot38}$, or if we consider the soda-lime felspar alone, $Ab_{11}An_4$.

Sphene occurs extruded between the cleavage planes of biotite and in the cores of the zonal felspar crystals; it ranges in specific gravity from 3·28 to 3·5, the difference in density being due probably to difference in the quantity of iron present. With a powerful electric magnet it was found possible to separate a collection of grains of this mineral into two portions—one non-magnetic, of a whitish-grey colour with a tinge of cinnamon, the other magnetic and of a dark-grey tint; the latter contained a large percentage of iron, over 10 %, but I cannot give exact figures as I did not completely purify it from titanium oxide; the non-magnetic portion yielded scarcely a recognisable trace of iron.

Another heavy mineral besides sphene occurs in the rock, sometimes associated with it in the cores of the felspar, sometimes in independent crystals allotriomorphic towards the zonal felspar; they are transparent, of a honey-yellow colour, high refractive index, well-developed cleavage planes running with the length of the crystal, and a regular banded appearance resembling that of lamellar twinning; between crossed nicols the colour is a deep blue—extinction parallel to the cleavage—while the plane of the optic axes is at right angles to this direction. I do not know what it can well be, unless zoisite. This mineral led me into a curious mistake—combining what I knew of its characters in a thin slice with the results of an incomplete analysis of sphene I took it for allanite, and so

described it in my preliminary account of the rock (28); I take the earliest opportunity of making this correction.

Magnetite occurs, both as a primary and secondary constituent; the primary magnetite presents rectangular or square sections, either terminating sharply against the surrounding quartz and felspar or ending in a margin of sphene; in the latter case it is evidently titaniferous. A small quantity of iron pyrites occurs.

DYKES ASSOCIATED WITH THE AUGHRIM GRANITE.—Within a short distance of the boundary of the granite several parallel dykes of microgranite occur, which are unquestionably offshoots from the main mass. A description of one of these given in some detail occurs in my preliminary report, but I have since received, through the kindness of Mr. Kinahan, specimens of all the others, some eight in number, collected by him. They may all be described as microgranite, but differ in the fineness of texture of the ground-mass; in some the form of the constituents of the ground-mass can be distinguished under a No. 2 objective of Voigt and Hochgesang, in others not; these latter might, perhaps, be more appropriately termed porphyritic felstones.

I add short notes on the characters of five of these dykes, numbering them in order, beginning with that nearest the granite—

Dyke No. 1.—The matrix is microgranitic, consisting of granules of quartz and felspar very irregularly intergrown with one another, and of muscovite, which is present in considerable quantity. Idiomorphic crystals of plagioclase felspar and chloritised biotite are scattered porphyritically. Alteration products are abundant, and possess features of interest. Thus, there is an abundant development of calcite, which occurs either as comparatively large irregular grains lying in the matrix or more usually in small crystals forming part of the central area of the plagioclase felspar. Not less conspicuous is chlorite, which not only replaces biotite, but a large part of the interior of felspar crystals, sometimes in association with calcite, sometimes not; it forms characteristic radiate aggregates, a single one of which may be sometimes seen growing, as it were, in the interior of a felspar individual, though more commonly a vast number

are collected together into an irregular complex. The chlorite and calcite take the place that in the felspars of the main granite would be occupied by a granular opaque core, leaving the remainder of the felspar of a surprisingly fresh appearance.

In addition to the foregoing epidote and sphene are present as secondary minerals. Magnetite, in crystals and spherules, is also present.

Dyke No. 2.—This is almost identical in character with the preceding; any difference there may be lying in the slightly finer granulation of the ground-mass.

Dyke No. 3.—This rock differs considerably from the preceding; the matrix is exceedingly fine-grained, but still resolvable into distinct individuals of quartz, muscovite, and felspar; scattered through it are numerous perfectly idiomorphic crystals of remarkably fresh-looking felspar, generally zonal in structure, twinned sometimes on the Carlsbad and Baveno plans, and sometimes synthetically on the albite and pericline types. The most common forms present are (010), (110), (001). Some of the zonal crystals have been broken across and recemented by non-zonal felspar (fig. 6, p. 455). Complexes of chlorite, evidently derived from biotite, occur with associated magnetite, sphene, and zircon.

The margins of the felspar crystals are sometimes more or less regularly notched by the intrusion of small quartz grains from the matrix, rendering it difficult to trace the exact boundary of the felspar, the felspar substance seeming to extend outwards into the matrix, where it conjoins with the minute felspar individuals that contribute to form its complex mosaic.

There is a suggestion of fluidal arrangement in the tendency of the chlorite and muscovite to extend along certain lines in one direction; a directional tendency in the muscovite becomes very marked where it approaches the insprinkled felspar crystals: close to them it shows a concentration at certain points, usually the corners, the quartz and felspar grains there entering less into the admixture of the ground-mass. The size of the muscovite crystals is correspondingly increased, and they bend round the felspar at an angle with their previous direction in a very characteristic fashion; the porphyritic felspar shows no directional tendency, but its occasional fracture points to movements in the rock when it was fluid.

An analysis of this rock gave the following :—

Silica,	71·78
Alumina,	15.86
Ferric oxide,	4·19
Lime,	3·16
Magnesia,	0·50
Potash,	1·13
Soda,	4·1
Water (by loss on ignition),	1·17
Total,	101·89

Dyke No. 4.—This is so similar to the preceding as to call for no further notice.

Dyke No. 6.—The general character of this is also similar, but the insprinkled felspar crystals are much diminished in size, rarely more than one quarter as broad or long: they still retain their idiomorphic form and zonal structure. When a crystal as large as in the preceding two dykes occurs it is usually broken or corroded.

I have notes of a partial analysis of one of the Aughrim dykes, which I think must be either this one, or another somewhat farther away from the granite—I am not quite certain which; however, I append it, since it shows a further decrease in the proportion of lime present.

Silica,	71·20
Titanium oxide,	·29
Alumina,	17·34
Ferric oxide,	1·34
Lime,	1·71
Magnesia,	0·64

The presence of zonal felspar similar in character to that of the main exposure, and the correspondence in chemical composition of the third dyke with the neighbouring granite, together with the parallelism of the dykes to each other and to the boundary of the neighbouring mass, combine to demonstrate that the dykes are offshoots from the granite. It becomes, therefore, of interest to compare them with a view to elucidating their

history: biotite complexes with zircons, and apatite are present in all, and up to the time of the completion of these all had, no doubt, a common history; zonal felspar is present in all, but in smaller crystals in the outermost dykes than in the parent rock. The common history probably extended, therefore, up to the period when the zonal felspar was in process of growth; then divergence set in; something occurred which caused the mother liquor of the dyke-rock to rapidly crystallize out into a fine-grained base of quartz, muscovite, and felspar (which never exhibits the structure of microcline), while that of the parent rock gave rise to large quartz grains and microcline. The event which primarily led to this was the injection of the dyke material into the surrounding schists, which by diminishing the ratio between the mass and its surface led to an increase in the rate of cooling, thus to more rapid crystallization, and by consequence to the formation of a fine-grained matrix. It is also possible that the material squeezed from the parent magma was comparatively richer in mother liquor and poorer in formed material than that which remained behind; if so this would account for the slightly greater acidity of the dykes as compared with the granite. I must confess for myself, however, that I find it somewhat difficult to picture the mechanism by which the magma should part with the mother liquor more readily than with the crystals, unless it had already partly consolidated, and in that case one would expect greater differences to result. I fancy, therefore, in this case the magma of the dykes was as nearly as possible identical with that of the larger mass.

VEINS OF WHITE GRANITE.—In the granite of Aughrim, as elsewhere commonly in the district, veins of a fine-grained white granite traverse the mass of the main rock. One of these, about 12 mm. in breadth, occurring in the Aughrim granite was selected for examination. Its boundaries from the surrounding granite are very definite to the unaided eye, and can be readily traced under the microscope, though the ends of felspar crystals of the main rock sometimes project across the dividing line into the vein. The substance of the vein is a most disorderly aggregate of quartz, muscovite, and felspar, apparently albite; titaniferous magnetite is present, but no microcline nor biotite. The quartz and muscovite predominate: the former in scattered grains rarely forming a mosaic; the latter in crystals filling up the spaces

between the quartz, and presenting very irregular outlines. The surrounding granite is of the usual type, but presents certain distinctive peculiarities, which can most briefly be summed up by saying that it looks under the microscope as though the component grains had been separated from each other, and white granite substance injected between them. Thus, the margins of the quartz grains are bordered by fine-grained white granite, and minute grains of felspar lie within them irregularly spotted about near the margin. Similarly minute grains of quartz are included in the marginal portion of some of the felspar crystal; but there is no trace of micropegmatisation, possibly because the two minerals have not simultaneously intergrown, but one has been subsequently introduced into the other. Again, in a single individual of quartz, forming one of a quartz mosaic, a crack occurs, which is filled in with minute flakes of muscovite, grains of quartz, and felspar—indeed, with what is practically fine-grained white granite—proving that after consolidation of the quartz it was broken across and white granite introduced into the fracture. Similar strings of white granite may be traced through crystals of microcline. In one instance a small string of white granite can be traced extending from the vein into the surrounding granite. The question naturally arises as to whether the vein has been supplied from the surrounding granite or whether it has been injected into it from below. Evidently from the sharpness with which the sides of the crack which the vein fills are maintained, the chief granite had consolidated before the crack was produced; this is also proved by the little thread of white granite which breaks through a single grain of quartz, as mentioned above. Even the microcline, the last constituent to consolidate, had crystallized out before the origin of the vein. It does not follow, however, that if we could trace the vein far enough downwards that we should find these relations maintained; on the contrary we might expect that any sudden yielding of the just cooled granite to tension arising from contraction would propagate itself downwards till it entered regions where some of the mother liquor of the rock would be squeezed out under pressure. This acid residuum would then fill the crack and enter partly by corrosion and partly by capillarity into the surrounding rock, and thus produce those alterations which have occurred in the present instance.

AUGHRIM GRANITE AT ITS JUNCTION WITH THE ORDOVICIAN SCHIST.—Near its contact with the schists the granite has undergone a considerable amount of alteration; the felspar is highly kaolinised, and converted into secondary muscovite, so that the lamellar twinning and zonal structure can only occasionally be made out. A replacement of felspar substance by quartz may sometimes be observed. The biotite has been completely converted into chlorite, but it frequently retains its original form, even when its parallel platy structure is replaced by the radiate structure of the chlorite. Muscovite is present in increased quantity, the sphene resulting from the alteration of ilmenite occurs in comparatively large crystals. As so often happens at the junction of igneous rocks with the surrounding country, a good deal of pyrites has been introduced into the rock: it takes the form of cubes and spherules; secondary quartz is associated with this mineral. The original quartz presents undulose extinction—the only sign of pressure alteration to be detected. It is worth noticing that the pleochroic aureoles around zircon, which were present in the biotite, are still preserved in the resulting chlorite. Pyrites occurs in large quantities in the adjacent schist, near the line of contact. The alteration thus affecting the granite at its junction can be almost wholly, if not entirely, explained as the result of the action of subaerial waters finding their way down between the junction of the granite with the schist. Possibly, however, some change may have been produced at a time when the granite was in a heated state; certainly it had at this period an effect on the schist, in which andalusite has been developed along with other minerals under the influence of the granite. A certain amount of pressure may have affected the granite, producing the undulose extinction of the quartz; but if so it was not the pressure which gave rise to the foliation of the schists, for the contorted folds of mica and other minerals characterizing these pass through the crystals of andalusite without any change in direction, proving that the development of the andalusite, which we must refer to the period when the granite was first injected, took place after the contortion and cleavage of the Ordovician rocks.

ALTERATION OF THE SCHISTS.—A few yards from the granite the schist possesses an extremely fine-grained texture, consisting for the most part of

minute crystals of muscovite, which form a perfect felt; small, nearly opaque, white grains of an undetermined mineral are mingled with this and granules of pyrites; many of the pyrites granules run parallel with the schistosity. In places the muscovite crystals acquire a larger size, forming very brightly illuminated spots between crossed nicols. Proceeding towards the granite the crystals of muscovite become larger; brown biotite puts in an appearance, usually in clusters of crystals thickly strewn, but not in contact; chlorite occurs, and crystals of andalusite, which is not pleochroic; the andalusite retains the same structure as the muscovite felt, the outlines of the individual muscovite crystals can be clearly traced in it, but their substance has been changed into that of andalusite—a change the reverse of that which occurs when the andalusite itself is subjected to earth pressure. Granules of pyrites and an occasional flake of biotite are included in the andalusite. Within a foot or two of the granite a wonderful change occurs—the muscovite felt is broken up into patches and streaks, in the midst of which radiating groups of chlorite are developed, and through which crystal-grains of quartz are scattered; between the patches are mosaics of quartz, large crystals of muscovite and chlorite, together with striated felspar, evidently an invasion of the felted muscovite rock by the granite substance. Apparently no solution has occurred; quartz and chlorite, as usually happens, have crystallized out together from the fluid, and occasionally plagioclase felspar has been added to the complex.

The rock actually in contact with the granite does not present such an interesting change as the preceding; the muscovite felt still retains its original character, but as in the last case it is broken up into patches, a perfect network of quartz grains traversing it, the quartz often of large size includes crystals of chlorite and granules of pyrites; and large crystals of muscovite are abundant, which often form a cluster in the middle of the quartz. From the foregoing it would appear clear that the granitic intrusion took place subsequently to the foliation of the Ordovician rocks.

CUSHBAWN (CaO 3·01; K_2O 2·27; Na_2O 3·39 (Haughton)).—This is a somewhat coarse-grained rock, the most obvious constituents of which are grains of quartz and idiomorphic felspar. Biotite occurs in considerably

altered crystals, rarely presenting a brown colour, almost always either green in tint, or colourless, as a result of bleaching; sphene commonly occurs as a product of its alteration, and sometimes epidote. Magnetite appears to have formed a primary constituent of the rock; it is now converted into a deep reddish brown iron oxide (without associated titanite) which retains the form of the original magnetite. The plagioclase felspar presents numerous idiomorphic rectangular sections (at right angles to *pg'*) and some hexagonal ones; it is greatly altered by the development of kaolin and secondary muscovite, the alteration as usual affecting the centre rather than the exterior of the crystals, so that an opaque core may be surrounded by a clear fresh apparently unchanged margin; a little calcite may sometimes be observed as a product of decomposition within the centre of the felspar. In making use of Dr. Haughton's analysis for calculating the proportions of the different kinds of felspar present in the rock, I shall assume that only 8 °/₀ of biotite is present, for there is almost certainly not more than in the Aughrim rock, which contains only 7·1 °/₀. On this supposition I obtain the following results :—

Orthoclase, - -	7·87 °/₀	141	Relative number of molecules.
Albite, - - -	26·73 ,,	509	,,
Anorthite, - -	13·35 ,,	240	,,

The ratio of albite to anorthite is thus very nearly as 2 : 1, corresponding to andesine of specific gravity 2·671.

Orthoclase occurs in ill-defined crystals, which do not appear to be idiomorphic. Microcline is absent. Quartz is present solely in granitic grains, which sometimes show slight undulose extinction. A small quantity of muscovite difficult to distinguish from bleached biotite is to be met with, and though strictly speaking this rock must be termed a granite, yet it is not far removed from granitite, and may be regarded as forming a link between the granitites and granites proper.

COOLBOY (CaO 2·7; K_2O 2·61; Na_2O 5·10 (Haughton)).—The soda-granite of this locality is very similar to that of Aughrim, previously

described. The felspar contents calculated in the same way as in the case of the Cushbawn rock are as follows :—

Orthoclase, - -	9·88 °/₀	173	Relative number of molecules.
Albite - - -	41·1 ,,	784	,,
Anorthite, - -	11·8 ,,	212	,,

This gives the formula $Or_5\ Ab_{20}\ An_6$.

Zonal structure prevails among the plagioclase felspars, which are idiomorphic, and in most respects similar to those of the Aughrim granite; microcline occurs in small quantity, but always as an allotriomorphic infilling material. Primary muscovite is present, usually in association with biotite. The quartz which is rendered very dusty by minute grains of residual minerals, has suffered considerably from dynamometamorphism, and usually gives undulose extinction. No micropegmatite is present.

Beautiful contact specimens of this rock are preserved in the Trinity College Museum. One of these furnished a slice in which the adjacent schist occurs in close association with the granite, which appears to have suffered no change in texture or otherwise as a consequence of the contact; the felspar of the granite usually terminates against the schist idiomorphically, but sometimes includes some of the constituents of the schist, particularly flakes of biotite. The schist consists of biotite (of the same character, so far as microscopic investigation can determine, as that of the granite), of muscovite, of a mosaic of quartz and felspar, and of elongated grains of garnet, extended like the other mineral constituents in a direction parallel to the plane of junction. Grains and rods of magnetite run in lines parallel to the schistosity, and traverse the garnets when these lie in their path. The garnets are cracked across at right angles to the schistosity.

BALLYNACLASH.—(CaO 2·25; K_2O 2·40; Na_2O 4·08 (Haughton)).—A medium-grained soda-granite, consisting of biotite, with zircon and apatite, and an excessive quantity of secondary sphene, of idiomorphic felspar with zonal structure, muscovitised, kaolinised, and containing a good

deal of secondary sphene, of quartz in granitic grains, much fractured, and exhibiting undulose extinction, and of microcline, which occurs in no large quantity as an infilling substance.

The rock is a good deal altered by the weather; but little of the biotite retains its brown colour: it is either green or bleached, or converted into chlorite. A small quantity of muscovite is associated with it. Hornblende is not present.

The quantity of sphene in the rock is so great as to render doubtful the value found for lime in Dr. Haughton's analysis, in which titanium oxide is not taken into account. Making use of it, however, in the way we have adopted, I find the following values for the felspars:—

Potash felspar,	-	11·09	1993 molecules,	or 1.
Soda felspar, -	-	32·71	6235 ,,	or 3·74.
Lime felspar, -	-	9·294	1668 ,,	or 1·2.
		53·094		

Considering only the soda and lime felspars we obtain the formula Ab_3An for the average soda-lime felspar present.

CROGHAN KINSHELA.—(CaO 0·67, K_2O 4·32, Na_2O 3·51; and CaO 0·89, K_2O 0·40, Na_2O 5·58 (Haughton)).

The rock to which the second set of figures given above refers has been already described by me (27). Calculating from the total amount of lime present I found 4·41°/₀ of anorthite, but in making the calculation I omitted to deduct for lime present as apatite. As the amount of phosphoric acid has not been determined, I do not know what reduction to make on its account, but I fancy that when it has been allowed for very little will be left for anorthite. A deduction from the potash on account of the biotite present would similarly leave very little of this constituent for orthoclase.

In one slice of the rock the felspar is present in idiomorphic crystals, some of which present microperthitic structure, and others synthetic twinning on the albite, and rarely on the pericline plan: quartz occurs in rounded grains, occasionally penetrated by apophyses of felspar. Well developed micropegmatitic structure is characteristic. Each grain of quartz is the centre of a micropegmatitic area; it is surrounded by a number of

crystals of felspar, which are pegmatised for a variable distance from their contact with the quartz grain, sometimes the pegmatitic structure extends completely across them, sometimes it stops half-way or sooner. Sometimes these relations are reversed; a crystal of felspar is included within a grain of quartz, and into which it sends pegmatite veins. Biotite is present or rather is represented by chlorite, with associated sphene and magnetite.

Signs of the action of pressure are numerous; the lamellæ of synthetic twins are frequently bent, and undulating, and the quartz extinguishes in undulose fashion.

A slice from another example, preserved in Trinity College Museum, probably one of those analysed by Dr. Haughton, differs in character from the preceding by the absence of pegmatitic structure: biotite not converted into chlorite is present, and associated with it are remarkably large crystals of apatite. Muscovite is interlaminated with it, and zircons with pleochroic aureoles are scattered through it. The felspar, otherwise very similar to that of the previously described slice, does not possess idiomorphic outlines, but the perthitic structure and lamellar twinning are retained. Numerous cracks extend through the rock, traversing several constituents in their course; they are filled with secondary felspar, quartz, and muscovite. At its margins the quartz becomes granulitic, and undulose extinction is the rule: this slice, like the previous one, gives unmistakable evidence of considerable pressure action.

Two very good sections of the felspar cut more or less parallel to *g*, were observed; they gave extinction angles of 12° and 15°, in a positive direction, thus indicating albite, in which a little lime might be present.

ARKLOW ROCK, LITTLE.—(CaO 0·74, K_2O 3·18, Na_2O 3·84 (Haughton); CaO 2·2 K_2O 1·3 Na_2O 4·17 (Hatch)).

I am indebted for a good specimen of this rock to my friend Mr. Kinahan. Under the microscope it is seen to have suffered much from the weather: biotite occurs in considerable quantity, but it has lost all its colour. The iron ore associated with it is densely margined by sphene, and slender prisms of epidote are dispersed through it. So completely changed is the biotite and so similar to muscovite, that it ought rather to be identified with the latter mineral.

The felspar was originally present in fairly large and apparently idiomorphic crystals, but their margins are now difficult to trace; they retain traces of synthetic twinning on the albite plan, and rarely show zonal structure. Muscovite is richly developed within them; sphene and a little calcite also occur. Secondary muscovite is present also in the rock as independent radiating aggregates. The extinction of the lamellar twins of felspar in a zone at right angles to *pg* gave in some cases a large angle; thus in one case 22° was measured on one side of the twinning trace, and 25° on the other; a very common angle is 14°. Parallel extinction was observed in some of the lamellæ, the neighbours of which extinguished at 22°. This suggests an intergrowth of orthoclase. The quartz is present partly in large irregular grains, partly in small granules: indeed it appears to be both granitic and granulitic; cubical crystals of pyrites are present.

Dr. Hatch, since this was written, has published an account of the Little Arklow Rock,* giving an analysis which differs to some extent from that of Dr. Haughton: I place the two side by side for comparison.

Analysis of Little Arklow Rock.

	I. Haughton.	II. Hatch.
Silica,	72·40	71·6
Alumina,	17·24	16·9
Ferric oxide,	1·60	0·3
Ferrous oxide,	——	0·9
Lime,	0·74	2·2
Magnesia,	0.43	0·6
Potash,	3·18	1·3
Soda,	3·84	4·17
Water (loss on ignition),	0·80	1·1
Total,	100·23	99·6
Specific gravity,		2·607

Dr. Haughton's analyses are so very accurate that I conclude there

* Hatch, F. H.—On the Lower Silurian [Ordovician] Felsites of the South-east of Ireland. Geol. Mag., N. S., decade. 3, vol. VI., p. 546, 1889.

must have been some important difference between the two examples analyzed, and I am the more inclined to take this view from the fact that Dr. Hatch is led from the examination of his specimens to arrange the rock with the soda felsites, while those which I have examined are clearly granulitic granite, in which the granulitic character is quite subordinate. Dr. Hatch's estimate of the orthoclase in this rock, so far as it is based on his analysis, is evidently too high, as a considerable quantity of the potash must exist combined in the muscovite, and so far as this, whether primary or secondary, is derived from biotite, it must diminish the total orthoclase contents.

POTASH GRANITE OF BALLYKNOCKAN.—(CaO 2·65, K_2O 4·64, Na_2O 2·31 (Haughton)).

Potash felspar,	-	24·32 °/₀	4373 molecules.
Soda felspar, -	-	18·60 ,,	3545 ,,
Lime felspar,	-	11·28 ,,	2025 ,,
Total, -	-	54·10	

A somewhat coarse-grained granite, composed of dark brown biotite, muscovite, oligoclase, and microcline; the biotite is much corroded; apatite and zircon are of course associated with it. The muscovite is fairly abundant in large crystal plates, which are always accompanied by biotite; very thin lamellæ of magnetite commonly occur between its cleavage planes.

The soda-lime felspar occurs in idiomorphic crystals, a good deal altered by kaolnisation and the development of secondary muscovite, but still preserving traces of zonal structure. The parallel extinction of some of the crystals points to a position between oligoclase and andesine. From the table given above it would appear that the average soda-lime felspar is an andesine of the formula Ab_7An_4, but observations with the diffusion column show that it possesses a specific gravity of about 2·645, so that unless this is abnormally low owing to the presence of potash, the most characteristic soda-lime felspar must be an oligoclase; heavier felspars,

however, are also present, lying scattered in the diffusion column between quartz and calcite.*

Some crystals of oligoclase showing very close lamellar twinning complete their growth in a fringe of micropegmatite, which evidently originated before the consolidation of microcline was completed.

The crystals of microcline are numerous and large; their boundaries are usually allotriomorphic, but in some cases outlines, idiomorphic with respect to quartz, have been observed, and in addition, grains of quartz are sometimes included by microcline; in one instance a group of four or five in juxtaposition was observed in the centre of a large crystal.

The rectangular lattice structure is sometimes curiously modified as in the Three Rock granite by the presence of a third set of bands crossing the others at about 45°; this is possibly the result of pressure.

The quartz occurs in granitic grains, as well as in the form of micropegmatite. The grains appear to have crystallized out after the other constituents. They contain numerous planes of liquid and gas pores, and long, slender, straight, or undulating filament-like crystals, which have been described by Dr. Hull as the "trichites" of Zirkel. They are not confined to the quartz, but occur also in felspar. It is difficult to say what they are, possibly rutile; some of them are geniculated in a manner reminding one of that mineral. The extinction of the quartz is frequently undulose.

THREE ROCK—((*a*), CaO 1·34, K_2O 5·79, Na_2O 2·82; (*b*), CaO 2·04, K_2O 4·65, Na_2O 3·29; mean, CaO 1·69, K_2O 5·22, Na_2O 3·105 (Haughton)).

The granite of Three Rock Mountain is usually coarse-grained; and porphyritic, with large crystals of microcline and muscovite. Dr. Haughton's

* Professor Hull, Director of the Geological Survey of Ireland, has observed (13) "several small subcrystalline (*sic*) forms in thin slices," which, "from Dr. Haughton's analysis, and the occurrence of albite in the granite of Dalkey, he has little hesitation in identifying with albite." It will be seen that Dr. Haughton's analysis does not afford material for such a conclusion; and I may add that the crystals of oligoclase are not usually small as compared, say, with the grains of quartz, and they certainly are not subcrystalline. Since, however, Dr. Hull speaks of the quartz grains as "amorphous," he has doubtless views on the crystalline state of matter peculiar to himself.

analysis referred to above under (*a*) was of a coarser rock than that which gives the results under (*b*).

The mineral composition as estimated by weighing tracings of areas is as follows:—

	I. Areas °/₀.		II. Sp. Gr.		III. Weights.		IV. Weights °/₀
Mica, - - -	8·405	×	2.81	=	2362	or	8·93 °/₀
Soda-lime felspar, -	39·45	×	2·328	=	10406	,,	39·33 ,,
Microcline, - -	16·045	×	2·57	=	4121	,,	15·59 ,,
Quartz, - - -	36·10	×	2·65	=	9567	,,	36·16 ,,
	100·00				26456		100·00

From the figures of the third column it will be seen that from the estimate here made the theoretical specific gravity of the rock should be 2·646; by observation, Dr. Haughton found it to be 2·652. The approximation of our result is sufficiently close, considering that we have neglected to take the heavier minerals present, such as magnetite, apatite, and zircon, into account. The specific gravity of the mica was estimated as 2·81, since it consists chiefly of muscovite, which in this rock, according to Dr. Haughton, has a specific gravity of 2·771; but as it includes some biotite, to the extent of say one part to ten of muscovite, we have adopted a correspondingly higher value. From the percentage of mica found above we can estimate the quantity by which the total potash and soda are to be reduced in calculating out the felspars. From the results of chemical analysis I find the following:—

Potash felspar, - -	25·22 °/₀	4745	molecules.
Soda felspar, - -	24·95 ,,	4788	,,
Lime felspar, - - -	7·594 ,,	1084	,,
Total, - -	57·764	Ratio Or_{19} Ab_{19} An_4.	

The total felspar found by weighing areas is 55·5 °/₀, or about 2·3 °/₀ less than that indicated by analysis—not a great difference when all the uncertainties of the several calculations are taken into account. The difference in the respective estimates of the microcline is more marked, amounting to nearly 10 °/₀; this may be partly due to the potash felspar contributing somewhat to the composition of the soda-lime felspar, and

partly also to my having possibly confused some sections of microcline cut parallel to the plane *g* with those of soda-lime felspar—not a difficult mistake to make.

The approximate formula for the soda-lime felspar, supposing it to be collected together in crystals of one composition, is Ab_5 An. Observations with a diffusion column show that the greater part of the soda-lime felspar has a specific gravity of 2·64.

In making a separation of the mineral constituents it was observed that the merest trace of felspar heavier than quartz was obtained; with the quartz a little cordierite fell. This mineral has been described by Mr. Joly as occurring with beryls at Glencullen (14). A considerable fall of felspar was obtained at 2·627. This was repeatedly re-separated and subjected to analysis. It yielded the following:—

Silica,	67·17	%
Alumina,	20·50	,,
Ferric oxide,	0·22	,,
Lime,	1·61	,,
Magnesia,	trace	
Soda,	10·16	,,
Potash,	0·65	,,
Water,	0·31	,, (by loss on ignition).
Total,	100·62	

Calculating the felspar from the alkalies and lime we get:—

Albite,	85·81	%	1636 molecules.
Anorthite,	8·00	,,	143 ,,
Orthoclase,	3·84	,,	69 ,,
Total,	97·65		

The approximate formula is thus, $Or_1Ab_{24}An_2$, and the felspar is evidently a good albite, with a probable formula of $Ab_{12}An_1$.

Under the microscope zircons are abundantly seen, sphene has not been observed, and apatite is not very conspicuous. Biotite occurs included in muscovite and bordering it, and sometimes in independent flakes. Muscovite is abundant in large idiomorphic crystals, the zonal structure of which

and their relations to biotite have been already described (p. 448); delicate lamellæ of magnetite are not infrequent between the cleavage planes, which are sometimes curved as a result of dynamo-metamorphism. The soda-lime felspar occurs in highly kaolinised zonal crystals, sometimes presenting synthetic twinning, sometimes not; the extinction angles are, as a rule, small, pointing to oligoclase. The crystals, not seldom, complete their growth in a fringe of micropegmatite, the surface of which is rounded in such a manner as mammillations would present when cut across; this mammillated surface is idiomorphic to microcline, as in the case of the Ballyknockan granite, and in one instance a completely pegmatised crystal of oligoclase or albite was observed lying in the centre of a patch of microcline which completely enclosed it. In some cases a "microclinisation" of zonal felspar was observed, the microcline having eaten out, as it were, a portion of the soda-lime material. Microcline occurs in large irregular plates, which are crowded with included crystals and fragments of the earlier-formed constituents of the rock; soda-lime felspars in particular are richly strewn through it, and offer a contrast striking by their weathered appearance to the fresh and well-preserved microcline. As in other granites of the district, which bear marks of pressure action, the rectangular lattice-work of the microcline is sometimes distorted and sometimes crossed by a third set of colour stripes running at about 45° with the normal ones. The quartz occurs in granitic and granulitic grains; it is much fractured and gives undulose extinction. The quartz-areas do not include numerous other minerals as does the omnivorous microcline; on the contrary they are singularly exclusive, apparently because they have been the last to crystallize out. Previous to their consolidation, the other constituents had already formed a coherent mass full of irregular cavities, which the quartz now fills.

POULMOUNTY.—(CaO 1·48, K_2O 5·13, Na_2O 2·97 (Haughton)).

Potash felspar, - - -	25·753 °/₀	4627 molecules.
Soda felspar, - - -	24·409 ,,	4653 ,,
Lime felspar, - - -	5·467 ,,	981 ,,
Total, - - -	56·129	Ratio, Or_{19}, Ab_{19}, An_4.

This rock is distinguished by the excessive corrosion which most of its

constituents have undergone; corroded biotite and muscovite are succeeded by corroded albite, which seldom presents idiomorphic outlines owing to the extent to which it has been eaten into by orthoclase and quartz; the albite similarly eats into the biotite, which is also attacked by the muscovite. The irregularity of the albite crystals is enhanced by their irregular intergrowth one with another. Irregular interpenetration of quartz and orthoclase also occurs. The albite gives symmetrical extinction angles of 8° to 11°: no doubt, oligoclase is present in addition to albite.

Contact action is shown by the presence of andalusite; dynamometamorphic action by the frequent fractures in the quartz and its undulose extinction, which frequently takes a banded character. Microcline structure is rare.

BLACKSTAIRS.—(CaO, 0·99, K_2O 4·80, Na_2O 3·18 (Haughton)).

Lime felspar, - - -	4·115	molecules,	738
Soda felspar, - - -	26·05	,,	4967
Potash felspar, - -	27·72	,,	4983
Total, - - -	57·885	Ratio, Or_{20}, Ab_{20}, An_3.	

The diffusion column gave a dense zone of microcline of specific gravity 2·56, then a continuous scattering down to 2·638, where a second dense zone occurred; a zone of quartz followed, with a few heavier felspar grains extended below it.

Under the microscope this granite much resembles that of Poulmounty; the albitic felspar presents extraordinary ragged and eroded outlines. It is often broken and re-cemented; its twin lamellæ are sometimes curved, and it is very liable to pegmatisation, the pegmatising veins not always being quartz, but sometimes microcline. The microcline occurs as a corroding and infilling material; its cross-hatching has generally been destroyed, and a curious, blotchy, and undulose extinction appears in its place. The quartz occurs in large grains which are fractured and give undulose extinction, and in small granules inextricably mixed up with the felspar constituents. The rock has evidently been subjected to considerable pressure, which has impressed a slight but not very marked parallelism or foliation upon it. Contact action is shown by the presence of small crystals of andalusite.

Some of the lamellar twins of felspar extinguish symmetrically at 15°. There is not much biotite, most of what there is occurring as remnants in the midst of muscovite, which is fairly abundant.

ROCKABILL.—(CaO 0·67, K_2O 7·92, Na_2O 0·54 (Haughton); K_2O 5·236, Na_2O 3·587 (Sollas)).

The mineral composition, as determined by weighing areas, is as follows :—

	Areas °/₀	Weights	Weights °/₀
Mica, - - -	6·06	1698	6.47
Felspar, - - -	68·14	17715	67·48
Quartz, - - -	25·80	6837	26·05
Total, - -	100·00	26250	100·00

In estimating the felspar from Dr. Haughton's analysis, results were obtained which did not agree with those given by observations of the diffusion column, and since the amount of potash found by Dr. Haughton's analysis is exceptionally large, and that of the soda as remarkably small, I thought it worth while to repeat the alkali determination, using for this purpose the same specimen of rock which Dr. Haughton had examined. The total amount of alkalies found by me is very nearly the same as that found by Dr. Haughton, but of the potash a much smaller, and of the soda a much larger proportion was obtained. To make certain that my analysis was a good one the soda was determined both by difference and directly, with closely accordant results: and both the potash and soda were afterwards examined spectroscopically; they were found to be well separated from each other, but a small quantity of lithia was found along with the soda—a result not quite unexpected, as it had been found necessary to weigh the mixed chlorides with great rapidity, so eagerly did they absorb water.

Sphene is almost absent from the rock, and apatite is not abundant; in calculating for the felspars no deduction has been made on their account. The mica has been taken at 10°/₀.

Proportion of the felspars present :—

Lime felspar, - - -	2·94	molecules,	5925
Soda felspar, - - -	29·50	,,	57500
Potash felspar, - - -	30·23	,,	54440
Total, - - -	62·72	Ratio, Or_{10}, Ab_{10}, An_1.	

The total quantity of felspar thus reckoned is in round numbers 5°/₀ less than that obtained from weighed tracings; possibly a not sufficiently large area was traced for exact results.

With a diffusion column a dense zone of felspar a little lighter than microcline floated highest; scattered grains extended down to the next zone which extended from a little above albite (sp. gr. 2·638) to a little below it. A few loose grains occurred below this zone, then followed a dense zone of quartz. The average specific gravity of the predominant soda-lime felspar may be taken as 2·634. It is, therefore, a good albite.

Biotite with abundant zircons occurs in small quantity. It has mostly lost its brown colour and become green, and numerous radiate groups of acicular crystals of epidote have been produced within it as a product of alteration. Muscovite in well-developed crystals is more abundant. It is usually associated with the biotite, from which it has evidently been partly derived. Both micas occur frequently as inclusions in all the other constituents of the rock. Primary muscovite with corroded outlines may not unfrequently be seen included in the midst of an albite crystal, to which it has not only served as a nucleus, but contributed material. Secondary muscovite is abundant in the felspars, but it is doubtful how far all the mica which is usually regarded as secondary really is so in fact. A remarkable case of inter-penetration is presented by a crystal of biotite which was observed lying at a little distance from a crystal of albite; both are similarly oriented, judging from the cleavage planes; the mica is prolonged beyond its general boundary in thin lamellæ, looking like very fine lines in section, and these can be traced for some distance into the felspar, where they become difficult to distinguish from the parallel lamellar twins,

(fig. 8). Here one would say a crystal of biotite had contributed to the formation of a crystal of albite, the *g* planes of which appear to have been determined by the *p* planes of the mica. If this be so it is easy to conceive that some of the muscovite plates lying parallel to the cleavages of the felspar in which they are included may also be residual. It cannot be denied that as a rule most of these mica plates are secondary, but it is quite possible that some are not. Biotite associated with muscovite sometimes forms a nucleus to albite crystals, and cases occur in which a crystal of muscovite including biotite has been deeply eaten into at the sides by felspar, as biotite is by muscovite.

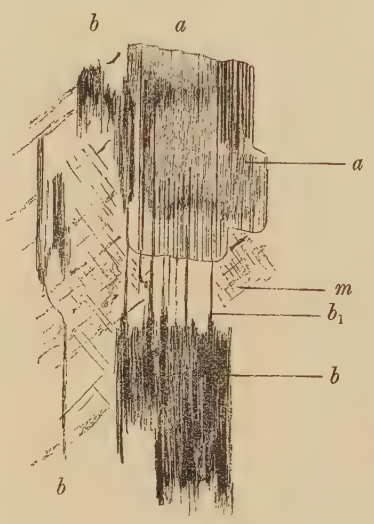


FIG. 8.

A corroded crystal of biotite (*b*), some of the lamellæ (b_1) of which extend into an adjacent crystal of albite (*a*); (*m*) microcline.

The two main felspars are microcline and albite. The latter, which contains a little lime, occurs in idiomorphic crystals, rarely zonal, usually repeatedly twinned. The twinning lamellation frequently fails over a portion of the crystal. Symmetrical extinction angles of 14° were observed. Corrosion by quartz has in some cases taken place. The microcline occurs in fairly large crystals; seen as irregular plates in section, they are traversed by a perfect network of albite veins, and include examples of all the other minerals, not excepting occasional grains of quartz. Sometimes a complex formed of a crystal of albite conjoined to one of biotite, and a grain of quartz (the whole forming a three-grained fragment of granitite) occurs as an inclusion in microcline.

The quartz occurs as grains, which in addition to planes of vapour cavities include numerous long slender rods of some undetermined mineral; from the low refractive index I should conclude certainly not rutile.

Contact action is indicated by occasional crystals of andalusite, dynamo-

metamorphic action by the occasional curvature of the lamellæ of twinned albite, and the undulose extinction of the quartz.

THE GNEISSOSE GRANITE OF ANN'S MOUNT.—The granite on the top of the hill near Ann's Mount, Tallaght, is distinctly foliated, the foliation being well seen in hand specimens. Thin slices were prepared for microscopic examination. In mineral composition it resembles the granite of Three Rock Mountain, consisting of a little biotite, a good deal of muscovite, oligoclase, and albite in idiomorphic crystals, and large porphyritic crystals of microcline, in which the idiomorphic albitic felspars are abundantly included. Micropegmatite is largely developed. Signs of crush are everywhere apparent. Both micas lie conformably with the irregular curved surfaces of foliation, except when they occur as enclosures in the large crystals of microcline, which have served to shield them from the effects of pressure. They form more or less continuous sheets, extending over a considerable area, in a section an inch and a-half long. A continuous line of mica running in an undulating fashion can be traced from one side to the other. These surfaces of mica appear to be planes of flow or sliding surfaces; their general appearance suggests this, and more particularly a characteristic habit they have of diverging on each side of lenticular less-crushed portions of the rock (after the fashion of microliths in the case of fluidal structure) on approaching a large crystal. The idiomorphic crystals of albitic felspar are rare, except as enclosures in microcline, and then radiating cracks sometimes proceed from them into the surrounding substance of their host. The microcline generally lies with its greatest length in the direction of the foliation planes. It is usually traversed by a multitude of fine cracks running across it at right angles to the foliation. The cracks are seldom quite rectilinear, and are usually more or less diverted on approaching the included albite crystals. Its cross hatching is frequently distorted or obliterated, and the extinction undulose. The quartz occurs chiefly in irregular flattened plates, extending parallel with the foliation, and sometimes broken across repeatedly, other minerals such as biotite having been injected into the cracks. Numerous planes of vapour cavities also extend

across them parallel with wider cracks. Micropegmatite usually occurs along the margins of the microcline.

THE SCALP.—The granite of the Scalp is all more or less affected by pressure, but naturally the effects are more pronounced near its junction with the Ordovician schists, where it assumes in places a perfectly gneissose structure. This is more particularly the case, as in almost all the crushed rocks of the district, near joint planes.

The mineral composition is similar to that of the Ann's Mount rock. Gliding surfaces run in an undulating fashion through the rock, dividing it up into a number of more or less lenticular masses or phacoids, which present in section the form of a double snake-like curve; the greater part of the phacoid usually consists of a larger or smaller crystal of felspar, the presence of which has in most cases determined its existence; in some cases an aggregate consisting of two or more crystals of felspar, and another of biotite, has led to the formation of the phacoid; in others quartz alone enters into its composition, and then the "snakes" are much flatter than usual.

In most cases the space between the cusps of the snake are filled with quartz, which there, as everywhere throughout the crushed rock, is of an extremely fine-grained granulitic character, the several minute constituent granules having very irregular arabesque outlines. When a large crystal of felspar, generally microcline, forms the greater part of a phacoid, the quartz at the cusps is much finer grained near the bounding curves than near the axis. Frequently, also, near the surface the quartz grains are distinctly elongated in the direction of the curves, which thus have the appearance of stream lines. The boundaries of the phacoids consist, to a very great extent, of mica, both muscovite and biotite (fig. 9, page 498). After this general account of the structure of the rock, we may proceed to describe, in order, the changes which have been effected in the characters of its constituents; beginning with the mica, including both biotite and muscovite, since both have been similarly affected. Where these occur as enclosures within a large crystal of felspar, they have escaped the action of pressure, but along the stream lines, where they are usually found, they have suffered mechanical, but not chemical change: crystals of the usual size have been reduced to small phacoids, which are drawn out at the ends into long fine lines,

often of extreme tenuity (this, of course, is the appearance in section; the fine lines represent thin films in the rock, which are visible when it is broken through). Large crystals lying with their cleavage planes transverse to the stream lines are rounded off where they encounter one of these lines, and the cleavage planes are bent in one direction, evidently that in which the rock on the other side of the stream line was

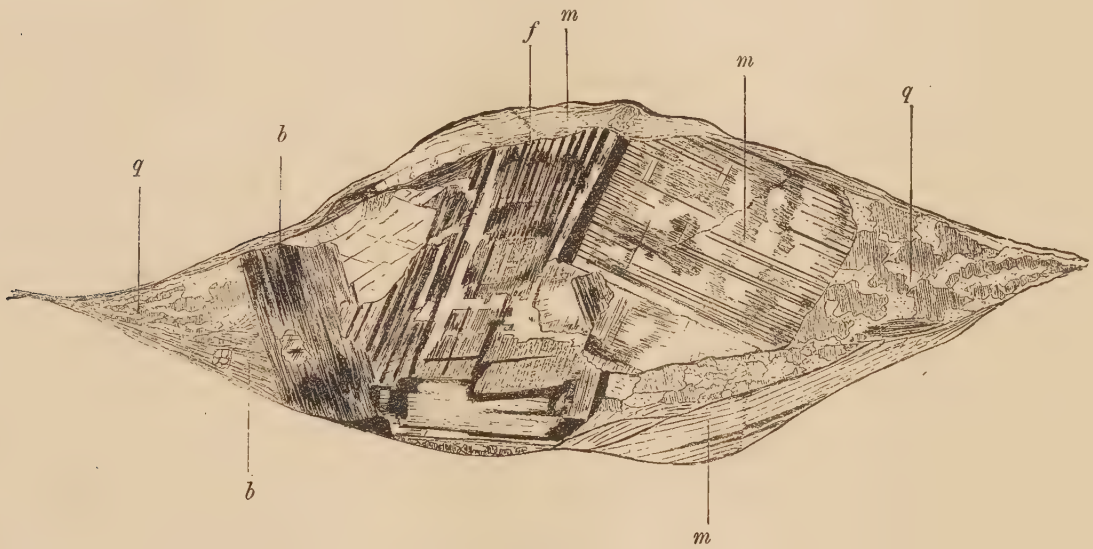


FIG. 9.

A single phacoid of crushed Granite. (*q*) Quartz mosaic at the cusps; (*b*) biotite; (*m*) muscovite; (*f*) felspar.

moving. The mica which has come within the range of the intestinal movement always shows undulose extinction. The felspar when in small crystals has either been completely crushed, or simply broken up into a few fragments, which are more or less separate from each other, sometimes with crushed material filling the cracks; in larger crystals the albitic twinning lamellæ, or the microcline cross-hatching, are obliterated over a part of the section, and the extinction has become undulose. In distinctly large crystals which consist of microcline and its usual enclosures of mica and idiomorphic albitic felspar, the effects of pressure manifest themselves partly by large

cracks which are not very common, and partly by innumerable very fine lines of fracture, which occur closer together in some places than others; they cross the felspar transversely to the direction of the stream lines, *i.e.* they lie in the direction of pressure (fig 10). Undulose extinction has sometimes, but not always, been produced. The quartz, however, is the mineral which has suffered most. Scarcely a single granitic grain has escaped being crushed to powder; the quartz mosaics of the original rock have been con-

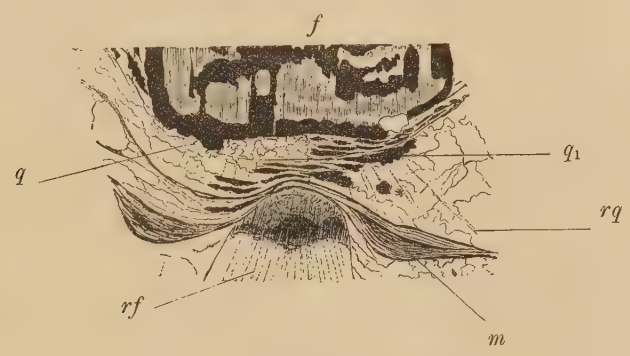


FIG. 10.

Crushing between two crystals of felspar (*f* and *rf*); *q* q_1 quartz mosaic; q_1 dark between crossed nicols shows elongation of the quartz in the line of shearing; *rq* radiating lines of vapour planes in the quartz; *m* mica; *rf* radiating planes of fracture in a felspar crystal, which is completely broken up at the rounded extremity ending against the quartz mosaic, *q* q_1.

verted into quartz phacoids with the finest of granulitic structures. The arabesque granules have been elongated into streaks which follow the direction of flow, and in some cases in a single phacoid one may observe jagged quartz streaks extending obliquely across from one side to the other with a false-bedded appearance, and suggesting a dragging-out action as the opposite surfaces of the phacoid sheared in opposite directions. In the crushed and re-crystallized quartz undulose extinction may still be observed, and in one case, under a No. 3 objective Voigt and Hochgesang, a granule of quartz, and an adjacent crystal of muscovite were observed with a common undulose extinction; occasionally, in flattened grains lying near a stream-line the undulose extinction was found to occur in bands lying at right angles to the foliation.

CONCLUSIONS.—In its main outlines the gneissose granite preserves the structure of the typical unchanged granite into which it gradually passes. Its earlier history was evidently the same, at least, up to the period of the consolidation of the quartz, for we can trace the same succession from biotite to muscovite, and from idiomorphic soda-lime felspar to microcline as we have established in all other instances. The quartz alone has lost its original form, but in the Ann's Mount rock, which is less altered than that of the Scalp, even this constituent is generally well enough preserved in its original form to show that it had no different relations to the other constituents than are met with in the normal granite. The evidence taken altogether, to my mind, is convincing that the crushed granite was originally in no essential respect different to the normal granite of the district.

The changed granite has suffered from mechanical deformation, by which extension has been produced in a direction known as that of foliation, and fracturing in a direction at right angles to this. Such a deformation could only be brought about by pressure acting on an already consolidated rock. A flow of viscous unconsolidated material might very well give parallelism of arrangement to certain of the constituents, as it has done in the case of the Killiney granite, but it could not produce a repeated parallel fracturing of felspar crystals at right angles to the line of flow without separation of the fragments. Further, as all the constituents except quartz retain sufficient traces of their form to show that they had certainly consolidated normally, and in the usual order, the only constituent that could have possibly retained a fluid state at the time of deformation would, on the hypothesis of viscous flow, have been quartz, but we have a good deal of evidence to show that this consolidates contemporaneously with microcline, and, hence, since the microcline had indubitably already consolidated before the deformation, we may conclude that the quartz had also.

The effect of pressure appears to have been wholly mechanical, if we may include a partial solution and re-crystallization under this head.

The direction of the foliation planes in the granite coincides with that of the schistosity in the adjacent Ordovician rocks, and it may be therefore concluded that the granite, which is known to have been post-Ordovician as regards its intrusion, had already consolidated before the period of post-

Ordovician earth-movements had come to a close; it owes its schistosity to these movements; but whether they commenced after or during the consolidation of the granite there is nothing to indicate.

In attempting to trace the history of the foliated granite we must start from the rock in an uncrushed state. Near its boundaries the granite may be expected to present the rudely parallel arrangement of mica plates, that results from viscous flow near and parallel to a bounding surface. The quartz would occur chiefly in granite grains, arranged in mosaics. On the application of pressure, shearing evidently commenced along lines determined by the mica plates, and was accompanied by the crushing of the quartz mosaics, while the felspar as a rule yielded but little: the crushed material set flowing moved in stream-lines round the immersed felspar, which remains as the "eyes" in the "flaser" structure.

It is easy enough to understand how the mica determined the lines of shearing, but more difficult on the other hand to explain why the quartz was so much more easily crushed than the felspar. It is harder than the felspar, and if its mosaic structure implies the existence of numerous planes of separation along which movement might be set up, yet even with equal reason the cleavage planes of the felspar might be expected to serve the same purpose; nor can the presence of planes of vapour cavities furnish a sufficient cause, especially as we have weighty reasons for supposing these themselves to be, to a great extent, secondary, and the result of pressure. It would appear that we must fall back upon an assumed brittleness of the quartz as compared with felspar. It is obviously of importance that some one who has a testing machine at his disposition should make experiments as to the relative resistance to crushing of quartz and felspar. It may be observed that as the quartz is the last to crystallize out from solution, so it is the first to yield to pressure, and one may therefore inquire how far a re-solution of the quartz brought about by pressure might account for the observed facts. A careful examination of crushed specimens with regard to this question has convinced me, however, that in the first case it is certainly fracture and not solution which has led to disintegration. The supposed "brittleness" of the quartz seems to offer the best explanation of the facility with which it crushes. Although no direct

experiments have been made on the relative brittleness of quartz, there is a good deal of evidence that it is greater than in the case of felspar; the greater toughness of igneous rocks in which quartz is absent, such as diorites and syenites, is well known to road-makers. Rocks, like quartzite, wholly composed of this hard mineral, are peculiarly liable to powder when used as road metal. I notice that Professor Dewar alludes to the brittleness of quartz when describing an apparatus, into the construction of which it enters: he says, " . . . for the purpose of ensuring a uniform bearing for the quartz, which is very brittle."—(Proc. Royal Institution of Great Britain, vol. xii., p. 468, 1889.)

The effects of the granite of the main chain in producing contact metamorphism will be described in a subsequent communication.

Summary of Mineral Composition of the Granite.

As a result of his well-known mathematical and chemical examination of this question, Dr. Haughton found for the average mineral composition of the granite of the main mass the following:*—

Quartz, - - -	27·66 %
Felspar, - - -	52·94 ,,
White mica, - -	14·18 ,,
Black mica, - -	5·27 ,,

The felspar, however, is not to be understood as genuine felspar, but as a felspathic paste, the composition of which is calculated to be as follows:—

Silica, - - -	63·40
Alumina, - - -	17·66
Lime, - - -	2·81
Magnesia, - - -	0·13
Potash, - - -	5·84
Soda, - - -	4·97
Water, - - -	0·19

If we calculate out the felspars from this supposed paste, reckoning the magnesia as lime (0·13 MgO = 0·18 CaO, total lime = 2·99), and the

* See *antea*, p. 429.

water partly as potash (0·1 H_2O = 0·5 K_2O_5; total potash 6·34), and partly as soda (0·09 H_2O = 0·31 Na_2O; total soda 5·28), we obtain the results in the second column of the following table:—

	I.	II.	III.
Anorthite, - -	5·457	14·86	13·97
Albite, - -	8·687	44·59	41·98
Orthoclase, - -	6·872	37·45	34·49

while if we regard the magnesia and water as impurities, and neglect them, we obtain the numbers in the third column. Calculating back from these the percentage of silica and alumina that they indicate we have the following:—

	Anorthite.	Albite.	Orthoclase.	Total.
Silica, - -	6·414	30·63	24·24	61·28
or, - -	6·028	28·83	22·325	57·183
Alumina, - -	5·457	8·687	6·872	21·016
or, - -	5·129	8·177	6·329	19·635

In either case it will be seen that the alumina required for combination with the lime and alkalies is more than Dr. Haughton's table allows, and again that the proportion of silica given in his table is more than the lime and alkalies require.

If we deduct the amount of silica (7·12) which is in excess of that required to form felspar from Dr. Haughton's felspathic paste, and reduce it to a percentage of the whole rock, we obtain the value 3·77, and this added to the quartz found by Dr. Haughton gives for the total percentage of this constituent 31·43 °/₀, a result closely concordant with the mean obtained from measurements. The following table summarizes the composition of three examples of the granite given previously:—

	Primary Mica.	Soda-lime Felspar.	Quartz.	Microcline.
Three Rock, - -	8·93	39·33	36·16	15·59
Aughrim, - -	7·33	51·14	31·79	9·19
Rockabill, - -	6·47	33·44	26·05	30·28

It may next be observed that the value found for mica by Dr. Haughton is much higher than that given by measurements. This is, no doubt, partly due to the neglect in the latter of secondary mica developed by alteration of the felspar. Of primary mica I find a mean of 7·6 °/₀.

Dr. Haughton's estimate is 19·43 °/₀, so that from these results it follows that of secondary muscovite no less than 11·8 °/₀ is present, or in other words, that about one-fifth of the original felspar substance has been converted into secondary mica. This result is probably too high, but even if we divide it by 2 we obtain a striking illustration of the change which the original felspar has undergone.

Treating the question in a broadly general way we may represent the facts as follows: The percentage composition of the granite of the main chain as given by Dr. Haughton, furnishes us with the general expressions:— 24 SiO_2, 3 Ac_2O_3, MsO, 3 Ha_2O. Of these twenty-four molecules of silica ten exist in the free state as quartz, neglecting the molecule of MsO (part of it exists in the sphene, apatite, biotite, and soda-lime felspar). The remaining fourteen are disposed of between two molecules of felspar with the generalized formula 6 SiO_2, Ac_2O_3, Ha_2O, and one-third of a molecule of muscovite with the general formula 6 SiO_2, 6 AcO_2Ha. If from molecules we calculate back to percentages, we obtain about 15 °/₀ of mica to 60 °/₀ of felspar, and since 7·5 °/₀ of the mica is primary, there remains 7·5 °/₀ of secondary mica, or only 4 °/₀ less than follows from Dr. Haughton's estimate.

It may be observed in passing that if all the bases were combined with silica to form felspar there would still remain an excess of eight molecules of free silica. In face of this the existence of magnetite and biotite as primary constituents of the rock has always been recognised as a very extraordinary fact.

Summary of the Distribution of the Felspars.

In the following tables the results we have already obtained in discussing the felspar contents of the different examples of granite are collected together for comparison.

SODA GRANITES AND GRANITITE.

		Ballinamuddagh.	Carnsore.	Aughrim.	Cushbawn.	Coolboy.	Ballinaclash.
Potash felspar,	-	1·65	3·4	0·73	0·6	0·84	1·2
Soda felspar,	-	1·7	3·9	2·76	2·1	2·1	3·7
Lime felspar,	-	1·0	1·0	1·0	1·0	1·0	1·0

POTASH GRANITES.

		Ballyknockan.	Three Rock.	Poulmounty.	Blackstairs.	Rockabill.
Potash felspar,	-	2·1	4·4	4·7	6·7	9·0
Soda felspar,	-	1·7	4·4	4·7	6·7	9·7
Lime felspar,	-	1·0	1·0	1·0	1·0	1·0

In the soda-granites the albite is always in excess of the orthoclase, but this is not the case in the potash granites, excepting in that of Rockabill. This is what might have been expected from what Dr. Haughton has already made known as to the chemical composition of these two classes of granite; but what, perhaps, is a little surprising is the fact, so clearly brought to light in the tables, of the predominance in all the granite of the district, soda and potash granite alike, of the soda-lime over potash felspar. Potash felspar has always been regarded as the dominant and characteristic felspar of granite. Exact investigation has of late years made us familiar with the presence of soda-lime felspar as an important ingredient, but this is, I believe, the first time that the granite of an extensive tract, one of the largest in the world, has been shown to everywhere contain a greater proportion of soda-lime felspar than of potash. I expect that a more exact investigation of granites in other areas will make us acquainted with frequent instances of the same excess of soda-lime over potash felspar.

Another relation shown by the table is the generally larger ratio of lime to potash felspar in the soda than in the potash granites. In this respect the Ballynockan rock is more closely related to the soda than the potash granites, but its considerable excess of potash over soda felspar shows that it is rightly relegated to the latter class.

Summary of the History of the Granite.

Before the post-Ordovician earth movements had entirely ceased the great mass of Leinster granite was intruded into Ordovician schists, and rose within a covering of these rocks till it attained a height of at least 3000 feet. That it was able under a pressure equivalent to that of a column of water a mile high to maintain the form of a high chain of mountains is to be attributed to the resistance of the envelope which

hemmed it in; and if this envelope be not sufficient, recourse may be had to the hypothesis of Reyer, according to which the granitic intrusion took place by successive impulses from below, separated from each other by sufficient intervals of time to enable the layers first forced out to acquire great viscosity or even solidity before being followed by others. It follows from this hypothesis that the granite which occupies the highest elevations was the last to be intruded.

It is difficult to believe that the intrusion could have occurred without escape of molten material at some points or lines of weakness in the covering rocks. If so the subterranean granite would have manifested itself at the surface by volcanic eruptions; but of volcanic ejectamenta emanating from it no trace has yet been recorded.

Thanks to modern methods of research, and chiefly to the use of the microscope, we are able to unfold the history of the consolidation of the granite with a completeness, even as to details, which is not a little remarkable. Yet, as might be expected, difficulties present themselves, and they will be considered later on. As a starting point is generally assumed, a homogeneous fluid-mixture, or magma, composed of the existing molecules of the rock in a state of dissociation; with loss of energy, the free molecules aggregated into symmetrically arranged clusters, or crystals, the composition of which varied with the flow of time—thus, successive crops of crystals resulted, the different species of minerals seggregating from the magma in a perfectly definite order, which is never inverted, at least not in a typical granite. At the same time the growth of a crystal was probably never continuous, but always interrupted, seggregation and dissociation alternating with each other rhythmically; longer intervals of growth being followed by probably shorter intervals of unbuilding, due partly probably to slight local developments of heat as the moving molecules fell into position in the crystal clusters. With the unceasing loss of energy seggregation, however, always finally prevailed, till from the homogeneous magma the differentiated heterogeneous rock was evolved. Proceeding to particulars we find, as the earliest-formed constituents, crystals of zircon, which include bubbles of steam, showing that at this very early period water was present in the magma. The apparent simplicity of the molecular structure of zircon,

its stability and high fusing point point to just these characters which we should expect to find in a molecular cluster extricated at a period when the temperature of the magma may be supposed to have been just commencing to fall; and if, as is possible, the crystallization of rutile preceded that of zircon, this would also harmonise with preconceived views. But it is not so easy to understand why the succeeding mineral to appear should have been apatite. The crystals of this mineral are small like those of zircon, and its composition appears to have altered with its growth, for its centre is frequently differently coloured to the exterior; pauses in its growth, and perhaps reversals, are indicated by its zonal structure. The next mineral to consolidate was magnetite, sometimes accompanied by ilmenite. Its opacity effectually conceals a zonal structure, if any such exists, but that its composition is not homogeneous is suggested by the slight admixture of titanic acid which it usually contains; its growth sometimes terminated in a marginal border of primary sphene. Possibly the magnetite which now exists in the rock is but an insignificant representative of a "magnetite stage," when this mineral, and perhaps other spinellids, had brought together the greater part of the iron and magnesia previously scattered through the magma. If such a state of things ever existed, we must next suppose that the greater part of this material disappeared under the action of silicic acid, to appear as biotite—the next mineral to make its appearance. This is by no means a homogeneous mineral; the pleochroic aureoles surrounding every crystal of zircon included by it suggest that much. The nature of these aureoles is not at present understood, but if they do not indicate an excess of spinellid rays in the biotite molecules they may possibly be accounted for by the assumed presence of some rare earth, like didymium, which one would not be surprised to meet with adjacent to zircons or orthite; the latter mineral, however, though present in some granite, is not generally met with in our district. As a further proof of want of homogeneity, I may mention that I found a marked difference for the value of the optic axial angle in the centre and near the edges of plates of biotite from Ballyellin. The biotite in many of the granites seems scarcely to have completed its growth before its destruction commenced, and simul-

taneously muscovite came into existence, building up its crystals about the fretted fragments of dissolving biotite. The history of the muscovite is evidently a changeful one; it certainly was not "formed all at once." Its exquisite zonal banding records a succession of stages of growth and solution, and the increase in the angle of its optic axes when traced from the middle to the edges of the six-sided plates, reveals a successive change in composition. Many biotite rays contributed to the structure of the first-arrested molecules, but as zone succeeded zone these gradually grew rarer, and the molecules continually approached nearer the ideally pure muscovite type. The muscovite stage was succeeded by a felspar stage; but in some cases, as in the granitite of Ballinamuddagh, the latter followed immediately upon that of biotite, the muscovite stage being omitted. In either case the mica already formed was attacked and partly destroyed by the free silica of the magma; its dissociated molecules entering into new combinations contributed to, if indeed they did not, initiate the formation of felspar. That in some cases they actually did this is suggested by the coincidence that one sometimes observes between the clinopinacoids of felspar and the basal planes of corroded mica (muscovite or biotite) which extend from without a felspar crystal into its centre. The more calcareous felspar was first excreted; with growth anorthite molecules became rarer, albite molecules more abundant, till in the final stages of growth nearly pure albite was deposited. The change sometimes occurred within the limits of a single crystal, sometimes in successive crops of different crystals. The felspar molecules as they settled down, arranging themselves in regular order like a number of little magnets, were subject to frequent reversal in the direction of their poles, and this proceeding along with changes in composition gave rise to the repeated zonal banding of the crystals, as well as to synthetic twinning. So fine and regular are the zonal layers in many cases that as one regards them one might almost fancy one hears the reversal of the poles ticking like a watch. Growth, however, was not uniform, nor uninterrupted. The rounding off of the angles of the zones indicates frequent solution alternating with deposition. With the formation of the soda-lime felspar one chapter in the history of the granite is brought to a close; subsequent events are more difficult to follow, and their order appears not to have been

the same in all cases. Sometimes, as in the Aughrim soda-granite, silica next separated out, and the crystals of resulting quartz lying near together met, as they increased by growth, along interfering boundaries which are rarely those of crystal faces, but usually characterized by great irregularity. After the production of these quartz mosaics, the potash felspar consolidated as microcline. Its growth was probably rapid, for it does not present zonal banding. In other cases the excretion of quartz commenced a little before the growth of zonal felspar had ceased, as is shown by a pegmatitic intergrowth of the two minerals along the margin of the felspar, but it was apparently arrested soon after it commenced, and microcline then came into existence and completed its consolidation, leaving the formation of quartz mosaics to complete the consolidation of the rock. The energy which had maintained the rock in the condition of a homogeneous magma had now been entirely dissipated, but a further dissipation of energy of a different kind then commenced. The potential energy conditioned by the proximity of carbonic acid and water with the bases of the magnetite, ilmenite, biotite, and felspar, started a series of chemical changes; as it became kinetic its dissipation commenced, and still continues, its completion belonging to a remote future, as that of consolidation to the remote past. As a result of these changes we have the magnetite converted into hematite and limonite, the biotite into chlorite and magnetite, the anorthite into calcite, and also in common with the albite and orthoclase into muscovite and kaolin, with elimination of silica.

The potential chemical energy of the granite cannot be spoken of by itself; it exists only in relation to the carbonic acid and introduced water. The energy of chemical combination results from the introduction of material from without. Another kind of work was also done upon the granite by energy from without, for very soon, geologically speaking, after its consolidation, it became subject to the pressure of those post-Ordovician earth movements which affected the province of Leinster simultaneously with a great part of the rest of Europe. As a result we find in many places, where the pressure had been most severe, a new structure superinduced upon the granite: it is no longer granite but gneiss.

Difficulties in the History.

The chief of these is the order of consolidation from magnetite to biotite, and from biotite to felspar. Why out of a total of twenty-four molecules of silica in the rock should eight of these exist in the free state as quartz, while ferroso-ferric oxide remains uncombined, or why in the presence of these free molecules should biotite be formed instead of felspar?

The subject requires experimental investigation, for no completely satisfactory explanation can be adduced. This will appear if we consider a few possible hypotheses.

No. 1, with the removal of bases from the magma, as they united with silica, the acidity of the magma would continually increase, so that silicates continually poorer in bases would be produced with the flow of time. But the excess of silica cannot be accounted for in such a manner; for, as we have already shown, were all the bases united with silica to form felspar (the most acid salt in the rock), there would still remain an excess of silica in the free state to the extent of eight molecules out of a total of twenty-four.

The presence of biotite in the rock raises the number of free silica molecules to ten, an increase of two only. So trifling an effect is quite disproportional to the result sometimes attributed to it.

No. 2. The potential of chemical union between silica and bases may vary in some unknown way with temperature or pressure or both. Thus at high temperatures the bases exhibit a greater attraction for each other than for silica and spinellids, such as magnetite result. At a lower temperature an attraction of bases for silica manifests itself so far as to lead to the formation of mica, in which, however, a tendency for bases to unite to bases is still displayed, as in the case of muscovite, the aluminium of which is united on the one hand to hydrogen or alkali bases, on the other to silica. At a still lower temperature the attraction of bases for silica is paramount, and they no longer exhibit any tendency to unite with one another. As a result, felspar, in which all the existing bonds of the basic radicles are saturated by silica, is produced.

As a consequence of this hypothesis a considerable quantity of spinellids would be produced in the first stages of cooling; the bases being thus locally accumulated would present a very small surface to the surrounding magma compared to that which they would have done had they been evenly diffused throughout it; the molecules of silica impinging on these spinellid clusters would carry away as many molecules of bases as they could hold, sufficient, say, for the formation of biotite, but as silica molecules continued to beat upon this, it would in turn become converted into felspar by the union of fresh silica molecules with it. So long as free silica could reach it, so long might its conversion into felspar be expected to continue, but the process would be brought to an end so soon as the felspar bounding it consolidated. Microscopic observation proves conclusively that the consolidation of biotite preceded that of felspar, and hence under the conditions of pressure that obtained the order of the fusing points of these minerals must have been reversed: this seems to be demanded whatever hypothesis we frame. From this discussion it would appear that the fundamental assumption with which it started leads to no conclusions inconsistent with the facts as we know them.

No. 3. The silica at present in the granite may not have all been present at the period when consolidation first commenced. It is difficult, however, to invent machinery by which additional silica might be supplied to the pre-granitic magma. It might be accomplished by starting with a magma of composition intermediate to that which would produce a granite and that which would produce a basic rock. By long standing the heavier constituents would sink down, and the lighter rise up, and the ratio of silica to bases in the upper portion might thus be increased till that which we find in granite was attained. But it is doubtful whether the viscosity of the parent magma would be low enough to permit of such a complete differentiation, and even if it were, the process will hardly perform all that is demanded of it.

The second suggestion most commends itself to my mind, but in the present state of our knowledge experiment seems more necessary than discussion. As an explanation of the difference between the potash and soda-granites, Dr. Haughton has made a passing suggestion that the soda-granite may have been produced by the addition of portions of

the surrounding "country" to the potash-granite; if the Ordovician slate were melted up in the right proportions with the potash-granite, something very similar to the soda-granite would result; but, as Dr. Haughton himself points out, the former granite must have lost some of its potash if this constituent is not to remain in excess. Dr. Haughton remarks that if we cannot have recourse to some such means of explanation, the difference between more acid and more basic rocks must depend upon some original difference in the constitution of the magma, and there is an end to discussion. This is certainly true, but while a "streakiness" of the magma seems to be the only way to explain such great differences as that between the main granite and the dykes of hornblende picrite which occur in its margin, yet, when, as in the present case, there appears to be some connection between the distribution of a rock and its mineral composition, one is naturally led to inquire whether a causal relation cannot be found. On the whole there is an increase in the proportion of lime felspar as we withdraw from the main granite, till at Ballinamuddagh we find a granitite richer in lime felspar than any granite in the district. Now, if these dykes be prolonged downwards they would probably be found to unite with the main granite at different distances below the ground: they take their origin from a lower level than the lowermost exposed margin of the great mass. Again, they are younger than the main mass. If, then, the viscosity of the parent magma is not so great as to entirely counteract the differentiating effect of gravity acting on minerals of different density, we should expect portions of the magma richer in soda-lime or lime felspar to sink in course of time to a lower level than those richer in silica and orthoclase. Let the magma so produced be forced upwards by successive pushes; then, since the earlier of these would give rise to the main chain of granite, this would naturally consist of the higher and lighter layers rich in potash: later pushes would inject the dykes upon its margin with material from a lower level, and consequently heavier, and richer in soda-lime felspars.

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